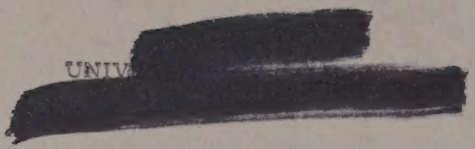


WASHINGTON GEOLOGICAL SURVEY

HENRY LANDES, State Geologist

BULLETIN No. 13

The Tertiary Formations of Western Washington

By CHARLES E. WEAVER

OLYMPIA, WASH.
FRANK M. LAMBORN PUBLIC PRINTER
1916

[redacted]

BOARD OF GEOLOGICAL SURVEY.

Governor Ernest Lister, *Chairman.*
Lieutenant Governor Louis F. Hart.
State Treasurer Edward Meath, *Secretary.*
President Henry Suzzallo.
President Ernest O. Holland.

Henry Landes, *State Geologist.*

LETTER OF TRANSMITTAL.

Governor Ernest Lister, Chairman, and Members of the Board of Geological Survey.

GENTLEMEN: I have the honor to submit herewith a report entitled "The Tertiary Formations of Western Washington," by Charles E. Weaver, with the recommendation that it be printed as Bulletin No. 13 of the Survey reports.

Very respectfully,

HENRY LANDES,
State Geologist.

University Station, Seattle, June 15, 1916.

TABLE OF CONTENTS.

	Page
ILLUSTRATIONS	10
INTRODUCTION	13
Field work and acknowledgments	13
Historical review	16
Bibliography	19
CHAPTER I. Topography and Drainage	54
General statement	54
CHAPTER II. Pre-Tertiary Formations	62
General statement	62
Old metamorphic series	63
Geographic distribution	63
Western slope of northern Cascades	63
Olympic mountains	65
Index granodiorite	65
Areal distribution	65
Character of outcrop	65
Petrographic description	66
Correlation	66
Hoh formation	67
Geographic distribution	67
Character of outcrops	68
Lithology	71
Geologic structure	72
Stratigraphy	74
Conditions of deposition	75
Fossils	76
Correlation	76
Chico formation	77
General statement	77
Geographic distribution	77
Character of outcrops	78
Lithology	78
Conditions of deposition	79
Geologic structure	79
CHAPTER III. Eocene Formations	81
General statement regarding the Tertiary as a whole	81
General statement of the Eocene	85
Geographic distribution	86
Lithology	88
Thickness	91
Stratigraphy	92
Fauna	93
Conditions of deposition	100
Climatic conditions	101

CHAPTER III. Eocene Formations—*Continued:* *Page*
Newcastle Hills-Grand Ridge Area ... 102
Geographic distribution ... 102
Character of outcrops ... 102
Lithology ... 105
Geologic structure ... 109
Stratigraphy ... 110
Green River Area ... 110
Geographic distribution ... 110
Lithology ... 111
Stratigraphy ... 117
Geologic structure ... 118
Conditions of deposition ... 118
Cedar Mountain Area ... 118
Geographic distribution ... 119
Stratigraphy ... 119
Geologic structure ... 120
Raging River Area ... 120
Geographic distribution ... 120
Stratigraphy ... 122
Geologic structure ... 125
Quimper Peninsula Area ... 125
Geographic distribution ... 126
Lithology ... 127
Geologic structure ... 129
Port Crescent Area ... 129
Geographic distribution ... 130
Lithology ... 130
Stratigraphy ... 131
Fauna ... 132
Geologic structure ... 133
Bald Hills Area ... 133
Geographic distribution ... 133
Character of outcrops ... 134
Lithology ... 136
Geologic structure ... 137
Black Hills Area ... 137
Geographic distribution ... 138
Character of outcrops ... 140
Lithology ... 141
Geologic structure ... 142
Elk Creek and Chehalis River Area ... 142
Geographic distribution ... 144
Character of outcrops ... 145
Divide between Columbia and Willapa rivers Area ... 145
Geographic distribution ... 147
Character of outcrops ... 152
Lithology ... 153
Geologic structure ... 153
Cathlamet-Germany Creek Area ... 153
Geographic distribution ... 154
Character of outcrops ... 156
Lithology ... 157
Geologic structure ... 157

CHAPTER III. Eocene Formations—*Continued:* Page
Ilwaco Area 157
Geographic distribution 157
Lithology 158
Geologic structure 159
Lower Cowlitz Valley Area 159
Geographic distribution 159
Character of outcrops 159
Stratigraphy 162
Geologic structure 163
CHAPTER IV. Oligocene Formations 164
General statement 164
Faunal Zones 166
Molopophorous lincolnensis Zone 166
Turritella porterensis Zone 167
Acila gettysburgensis Zone 168
List of Oligocene and lower Miocene faunas 170
Lithology 179
Stratigraphy 179
Conditions of deposition 183
King County-Restoration Point Area 186
Geographic distribution 186
Stratigraphy 188
Geologic structure 190
Quimper Peninsula Area 193
Geographic distribution 193
Geologic structure 194
Cape Flattery-Strait of Juan de Fuca Area 196
Geographic distribution 196
Geologic structure 197
Fauna 200
Grays Harbor Area 202
Geographic distribution 202
Geologic structure 204
Columbia River Area 207
Geographic distribution 207
Geologic structure 209
CHAPTER V. Miocene Formations 211
General statement 211
Lower Miocene 211
Geographic distribution 211
Geologic structure 212
Upper Miocene 213
Montesano formation 213
Geographic distribution 213
Lithology 213
Stratigraphy 214
Fauna 214
Faunal list of upper Miocene 216

CHAPTER V. Miocene Formations—*Continued:* Page
Grays Harbor Area ... 220
Geographic distribution ... 220
Character of outcrops ... 220
Lithology ... 223
Geologic structure ... 223
Stratigraphy ... 225
Quillayute Area ... 228
Geographic distribution ... 228
Character of outcrops ... 228
Lithology ... 228
Geologic structure ... 229
Fauna ... 229
Snoqualmie granodiorite ... 231
Enumclaw volcanic series ... 232
Geographic distribution ... 232
Lithology ... 233
Correlation ... 234
CHAPTER VI. Pleistocene Formations ... 236
General statement ... 236
Glacial deposits ... 236
General statement ... 236
Geographic distribution ... 236
Character of Pleistocene glaciation in western Washington ... 237
Terrace deposits ... 240
General statement ... 240
Fluviatile deposits ... 241
Marine Pleistocene deposits ... 243
Recent alluvial deposits ... 244
Tidal flat deposits ... 244
Sand dunes ... 244
CHAPTER VII. Geologic Structure and History ... 245
Geologic structure ... 245
General statement ... 245
Skagit-San Juan-Vancouver Island upwarp ... 245
New Castle-Olympic upwarp ... 246
Black Hills upwarp ... 247
Anticlines and synclines ... 248
Time of folding ... 250
Faults ... 251
Geologic history ... 252
CHAPTER VIII. Petroleum Deposits ... 259
General statement ... 259
Source of petroleum deposits ... 260
Geologic distribution of petroleum deposits ... 262
Relation of geologic structure to the occurrence of petroleum deposits ... 263
Possible occurrences of petroleum in western Washington ... 266
Cascade Mountains ... 267
Puget Sound Basin ... 267
Glacial deposits ... 267
Pre-glacial formations ... 268
North slope of the Olympic Mountains ... 271

CHAPTER VIII. PETROLEUM DEPOSITS—*Continued:* *Page*
Southwestern Washington 273
General statement 273
Pacific and Wahkiakum counties 274
Grays Harbor County 275
Cowlitz and Lewis counties 275
Thurston County 276
Western slope of the Olympic Peninsula 277
Source of the petroleum 280
Geologic conditions in special areas on the west coast of the Olympic Peninsula 281
Southwestern Clallam County 281
Queniult River district 283
Queets River district 285
Hoh River district 288
Quillayute River district 290
Ozette Lake district 292
Conclusions 292
Record of drilling operations 293
APPENDIX 299

ILLUSTRATIONS.

PLATES. *Facing Page*

I. Outline map of western Washington 15

II. Preliminary geologic map of western Washington..In Pocket

III. Areal and structural geologic map of southwestern Washington .....In Pocket

IV. Map A. General geologic and structural map of the western and northern margin of the Olympic Peninsula .....In Pocket

Map B. Areal and structural geologic map of a belt extending across Puget Sound Basin into the Cascade Mountains .....In Pocket

Map C. Areal and structural geologic map of the Quimper Peninsula .....In Pocket

Map D. Areal and structural geologic map of the Cathcart-Cherry Valley region.....In Pocket

V. Summit of Cascade Range showing characteristic topography 31

VI. View of Cascade Range taken from Mt. Rainier looking south toward Mt. Adams..... 40

VII. Mount Rainier looking north from Tatoosh Range..... 51

VIII. Tatoosh Range in the Cascade Mountains showing characteristic topography of the western slope..... 59

IX. Olympic Range as viewed from Seattle, showing low glacial plain of Puget Sound in foreground and Mt. Constance in background..... 61

X. Index Mountain situated on western slope of Cascade Range; Skykomish River in foreground..... 68

XI. Geologic and structural map of a portion of southwestern Clallam County..... 76

XII. Geologic and structural map of the region from Hoh Head southward to the mouth of Hoh River..... 81

XIII. Interbedded tuffs and shales in Eocene basalt series at Port Crescent, Clallam County..... 102

XIV. Eocene basalts exposed on west side of Cape Disappointment north of entrance to Columbia River..... 129

XV. Eocene basalts on east side of Cape Disappointment as viewed from Ilwaco..... 147

XVI. Geological and structural map of the region in the vicinity of the junction Olequa and Stillwater creeks, Lewis County 161

XVII. Geologic and structural map of Cape Flattery..... 164

XVIII. Oligocene sandstones exposed at the boat landing on Tatoosh Island 179

XIX. Oligocene sandstones exposed on the north shore of Cape Flattery, Tatoosh Island in the background.... 180

		Facing Page
XX.	Interbedded sandstones and shales of Oligocene age exposed on the south shore of Cape Flattery halfway between the Cape and Waatch Slough	185
XXI.	Coarse grained Oligocene sandstones and conglomerates showing cavernous weathering as exposed on an island on the south side of Cape Flattery	186
XXII.	Sandstones and conglomerates of Lower Miocene age as exposed east of Clallam Bay on the shore of the Strait of Juan de Fuca	194
XXIII.	Geologic and structural map southeast from Port Angeles, Clallam County	199
XXIV.	Geologic and structural map in the vicinity of the entrance to the Bremerton Navy Yard	200
XXV.	Geologic and structural map along portion of Nasel River, Pacific County	211
XXVI.	Geologic and structural map at the mouth of Queniult River	218
XXVII.	Upper Miocene formation as exposed at Cape Elizabeth, Grays Harbor County	223
XXVIII.	Figure A. Upper Miocene sandstones looking south from Cape Elizabeth toward Queniult River	231
	Figure B. Upper Miocene shale looking north from Point Grenville towards Queniult River	231
XXIX.	Figure A. Upper Miocene formations as exposed along beach north of Cape Elizabeth	239
	Figure B. Point Grenville, showing Eocene basalts on beach at low tide	239
XXX.	Structural geologic map of western Washington	250

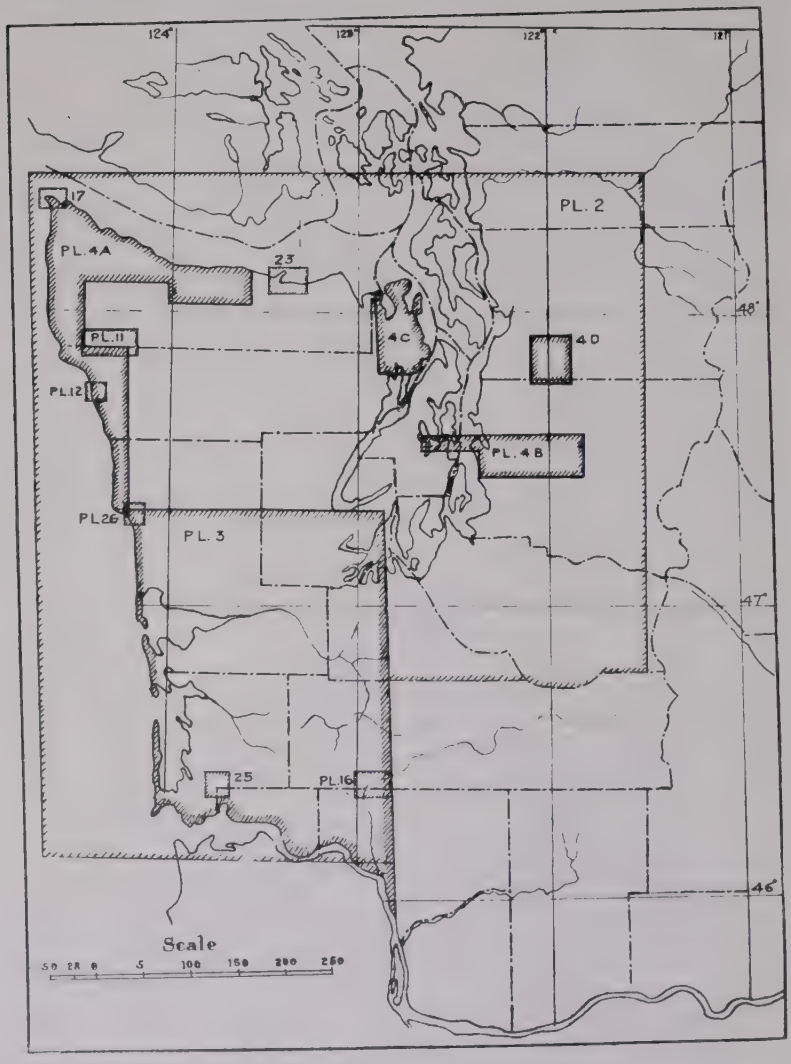
INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

The purpose of this report is to set forth the results of certain geological and palaeontological investigations of the Tertiary formations of Western Washington, carried on by the writer from 1907 to 1914. An attempt has been made to subdivide the Tertiary deposits upon a stratigraphical and palaeontological basis and in a preliminary manner to determine their areal distribution. A study has been made of the strata entering into each formation, the conditions under which they were deposited, the character of the fauna contained therein, and the structual conditions under which they appear. Geological maps accompany this report, upon which the larger part of the data has been assembled.

The area embraced in this report extends from the western foothills of the Cascade Mountains westerly to the Pacific Ocean and from Columbia River northward to the Strait of Juan de Fuca. The central portion of the Olympic Peninsula is excluded since only a hasty reconnoissance of this region has been made. Large portions of Western Washington have been examined in only a preliminary manner but other portions have been studied in minute detail. Survey traverses have been carried from Grays Harbor northward along the ocean shoreline to Cape Flattery and from that point easterly along the Strait to Dungeness River. Similar traverses have been made along all the more important streams where there were sufficient rock exposures to warrant such. Observations on the strike and dip of the sedimentary rocks were taken wherever possible and these were difinitely tied into stations on the lines of traverse. Detailed measurements were made in feet of each stratum exposed for the purpose of constructing stratigraphic sections.

Wherever possible collections of fossils were made and their exact localities tied into traverse survey lines. An effort was made to record the position of each individual stratum from



Outline Map of Western Washington.

which fossils were taken and refer each to some point on the line of traverse.

One large areal geological map of the western part of the state has been constructed on the scale of one inch to seven and one-half miles. Upon this the geographical distribution of the several formations involved have been represented by colors. In those places where the contact between formations can be definitely determined, the positions of the contact lines, as drawn on the map, are correct. In the intervening areas where the contact relations are obscure or entirely concealed, the contact lines have been drawn from the best evidence obtainable. In those regions where the pre-Pleistocene formations are concealed beneath a great thickness of glacial deposits, the surface geology has been designated as Pleistocene. However, where occasional outcrops of older formations project through the drift so as to indicate the probable age of the underlying formation, the pre-Pleistocene formations have been given the preference in mapping.

The area involved in southwestern Washington, from the south flanks of the Olympic Mountains to the Columbia, was mapped on a scale of one-half inch to the mile. A belt bordering the Olympic Peninsula from Grays Harbor northward around Cape Flattery and easterly to Port Angeles has been mapped on a similar scale. Another map has been constructed on the scale of one inch to the mile, extending west to east from Kitsap County across Seattle to the foothills of the Cascades. Upon this have been located all observations taken upon strike and dip, as well as contact lines between formations. The probable positions of all anticlines and synclines, where they can be determined, have been inserted. Where the contacts are definite they are represented by continuous lines; where only proximate, by broken lines.

Altogether about twenty months were spent in the field in areal mapping. The remaining time at odd intervals has been devoted to office work in preparing the maps and report. The writer has been assisted in the field work by Messrs. Charles R.

Fettke, Donald Ross, Olaf Stromme and T. A. Bonser in 1911, and by Charles Landes in 1913.

The collections of fossils have been identified and may be found in the Palaeontology collections of the University of Washington.

HISTORICAL REVIEW

The earliest records concerning the Tertiary formations of western Washington are to be found in the reports of the Wilkes Exploring Expedition, published in the year 1849. Examinations were made of the Tertiary formations along Columbia River by James D. Dana. Other members of his party examined the small valleys entering the Columbia from the north side, including the Cowlitz. Records were made of the occurrence of Tertiary strata along the shores of Puget Sound and in the vicinity of Bellingham. Collections of fossils were made at the town of Astoria. These were determined and described by T. A. Conrad, who recognized in them a very close relationship to the Miocene faunas of Maryland and Virginia.

After the appearance of this report very little was written concerning the geology or palaeontology of this region until 1867, when W. P. Blake published several articles on the coal formations of Washington Territory. In 1870 Dr. Robert Brown in a paper on the coal fields of the north Pacific coast describes coal deposits as appearing at Clallam Bay, Bellingham Bay, Cowlitz Valley, Issaquah, and Stillaguamish River. He regarded these as being of Tertiary age and also recognized the existence of Pleistocene lignite seams in the sea-cliffs of Puget Sound.

From 1870 to 1888 numerous short papers appeared referring to the geological conditions in the Cascade Mountains and along Columbia River, but are confined chiefly to a description of the basaltic lavas. In 1888 a report appeared by C. A. White on the Puget Group of Washington Territory, which was intended to include the coal bearing formation of King, Pierce and Whatcom counties. Collections of the brackish water fauna were made from the vicinity of Newcastle and Carbonado.

This formation was thought to bear a close relation to the Laramie. A collection of marine invertebrate fossils was made and reported as occurring in bluffs along the shores of Duwamish Valley. A list of these was given and they were referred to the Tejon horizon of the Eocene.

In 1892, in the Correlation Papers on the Eocene and Neocene of the United States, by Wm. B. Clark, W. H. Dall and G. D. Harris, reference was made to the Tertiary horizons of western Washington. The coal bearing horizon of the Puget Group was placed in the Eocene. It was suggested however that it might be in part of Cretaceous age. Miocene deposits were recognized as the equivalent of those at Astoria.

In 1906, reports in considerable detail were published by Bailey Willis on the Tertiary coal fields of King, Pierce and Whatcom counties. Detailed areal geologic mapping was begun and the structure of the formations in part worked out. Mr. Willis recognized the Puget Group as of Eocene age based on palaeobotanical determinations made by F. H. Knowlton. The Puget Group was described as having been deposited under estuarine conditions and to possess a thickness of over 12,000 feet. Marine Miocene deposits were referred to as resting unconformably upon the Eocene. In 1897 a report was published by J. P. Kimball on the physiographic geology of Puget Sound Basin. The larger part of this paper was devoted to a description of the glacial deposits; several localities were referred to where Eocene and Miocene outcrops were examined. In 1898 the volcanic rocks upon and around Mt. Rainier were described by George Otis Smith.

The older Mesozoic and Palaeozoic rocks of the western slope of the northern Cascades were described in a preliminary manner by I. C. Russell. These formations are of interest because they form the basement complex upon which the Tertiary strata rest.

In 1901 and 1902 the State Geological Survey of Washington was organized and field work was carried on for two years. The coal bearing horizons of the western part of the state were

described and their approximate areal extent represented upon a geological map. The distribution of all formations in the western part of the state as they were known at that time were shown upon this map.

A geological reconnoissance around the coast of the Olympic peninsula was made by Ralph Arnold in 1904. The results were published in 1906, in which he recognized the existence of an old series of partly metamorphosed sediments constituting the interior of the Olympic Mountains and the presence of Eocene, Oligocene and Miocene formations around its border. The Oligocene-Miocene strata were not differentiated and were referred to as the Clallam formation. On the Pacific coast of the Olympic peninsula certain fossiliferous deposits were noted on the Bogachiel and farther south at the mouth of the Queniult River. He regarded these as of upper Miocene or Pliocene age.

In the same year a paper appeared by the same author on the Pectens of the Pacific Coast, in which several new species were described from Washington. Reference was made to several fossiliferous deposits in Cowlitz and Chehalis valleys, as well as along the Strait of Juan de Fuca and in Puget Sound Basin across from Seattle. Later in 1909 Dr. Arnold published a paper on the environment of the Tertiary faunas of the Pacific Coast of the United States, in which the several Tertiary horizons of Washington were correlated with those in Oregon and California. Eocene, Oligocene, Miocene and Pliocene formations were recognized. In the same year Albert B. Reagan described the geologic formations in the vicinity of Bogachiel and Soleduck rivers and listed collections of fossils made there and along the Strait of Juan de Fuca. A considerable number of new species were placed on record.

In 1911 a paper published by W. H. Dall on the Miocene of Astoria and Coos Bay described several new species of marine invertebrates from Washington and a list of the fossils associated with them. These records are of great assistance in comparing the faunal zones of Washington with those of Oregon. During 1912 a paper appeared by Charles H. Clapp on the

geology of the southern end of Vancouver Island in which the geology of the Miocene deposits on the north shore of the Strait of Juan de Fuca were described.

In 1912 a paper was issued by the writer on the Tertiary Palaeontology of Western Washington, in which a considerable number of new species were described and figured. The geological horizons of the Tertiary, as recognized at that time, were given as well as a list of the characteristic fauna.

In 1912 a paper was issued by Arnold and Hannibal on the stratigraphy of the Tertiary formations of the Pacific Northwest. The formations of Oregon and Washington were correlated with one another and a new classification of the Tertiary horizons was set forth.

BIBLIOGRAPHY.

In the following list of references to the literature concerning the geology and palaeontology of western Washington only those papers have been quoted which have contributed some direct information concerning the Tertiary rocks. Numerous papers are in existence which refer to the topographical features or economic products of this part of the state, but which add no facts to Tertiary geology problems. The following references are regarded as important in a historical review of previous literature:

1845. Wilkes, Charles. Narrative of the United States Exploring Expedition. Vol. 4, pp. 313, 415, 424.

The only notes referring to westeern Washington geology are the "trap dikes" encountered on Cowlitz River and the basaltic flows on the banks of the Columbia.

1845. Greenhow, Robert. Geography of Oregon and Washington.

This work deals chiefly with the historical development and colonization of Oregon and Washington. A description is given of the geography of the western part of Washington as known at that time.

1849. Dana, James D. Notes on the geology of Washington Territory. Wilkes Exploring Expedition, volume X, pp. 616-623, 626-628, 658.

In this report a description is given of some of the geological features of Washington which was then a part of Oregon Territory. Basalt was observed as occurring in places along both sides of Columbia River. Tertiary sedimentaries are described at Astoria and across on the Washington side of the Columbia and are said to have a thickness of 1000 to 1200 feet. Similar strata are mentioned in Cowlitz River valley and along the shores of Puget Sound. Collections of fossils made by Dana have been described and figured by T. A. Conrad. Mr. Conrad's conclusions concerning the Miocene age of these faunas may well be quoted here:

"From the investigation of the fossils previously received from Mr. Townsend, I had arrived at the conclusion that they were of the geological era of the Miocene, and the specimens you sent confirm the opinion. I do not recognize, it is true, any recent species of the coast of California or elsewhere, but neither is there any shell of the Eocene period, nor has the group any resemblance to that of the Eocene. On the contrary, the forms are decidedly approximate to those of the Miocene period which occur in Great Britain and the United States. *Nucula divaricata*, for instance, closely resembles *N. cobboldiae* (Sowerby) of the English Miocene, and *Lucina acutilineata* can scarcely be distinguished from *L. contracta* (Say), a recent species of the Atlantic coast and fossil in the Miocene beds of Virginia. *Natica heros*, a shell of similar range, is quite as nearly related to the *N. saxea*. A similar number of species might be obtained from some of the Miocene localities of Maryland or Virginia and yet no recent species be observed among them. In the Eocene, and also in the Miocene strata, there are peculiar forms which obtain in Europe and America, and although the species differ, yet they are so nearly allied that this character alone, independent of the percentage of extinct forms, is quite a safe guide to the relative ages of remote fossiliferous rocks. On this foundation, I speak with confidence when I assign the fossils of the Columbia River to the era of the Miocene."

Gibbs, George. A reconnaissance of the country lying upon Shoalwater Bay and Puget Sound; upon the geology of the central portion of Washington Territory.—Pacific Railroad Reports, volume 1, pp. 465-486.

A general reconnaissance report on the geography of the region. Trachyte rocks are referred to as occurring about Mt. Rainier and St. Helens and gravels and sands in the Puget Sound region.

1856. Blake, William P. Review of a portion of the geological map of the United States and British Provinces.—American Journal of Science, second series, volume 22, pp. 383-388.

Reference is made to the fact that on Marcou's geological map of the United States the coal fields of Puget Sound are represented as upper Carboniferous. Mr. Blake states that "all the evidence that can be produced concerning the age of these deposits shows them to be Tertiary."

1857. Newberry, J. S. Coal of Bellingham Bay.—Pacific Railroad Reports, volume 6, part 2, pp. 53-68.

A section measured in the Bellingham Bay region gave "2000 feet of shales, sandstones and coal of which the coal presents the enormous aggregate of 110 feet." The strata of Bellingham Bay are believed to be of Miocene age and closely related to the shales of the Columbia and Coos Bay. Mention is made of the occurrence of fossil plants.

1857. Meek, F. B. On Cretaceous fossils from Vancouver and Sucia Islands.—Transactions, Albany Institute, volume 4, pp. 37-39.

1858. Shumard, B. F. Description of new fossils from the Tertiary formations of Oregon and Washington territories and the cretaceous of Vancouver Island. Transactions of the St. Louis Academy of Science, volume 1, pp. 120-125.

1859. Lesquereux, Leo. Species of fossil plants from Bellingham Bay, etc.—American Journal of Science, second series, volume 27, pp. 360-363.

This article describes several species of fossil plants collected by Dr. John Evans at Nanaimo and at Bellingham Bay. Those at the latter place are from the coal measures and are regarded as of Tertiary age.

1859. Heer, Oswald. Fossil plants of Vancouver and Bellingham Bay. —American Journal of Science, second series, volume 28, pp. 85-89.

Certain species of fossil leaves from the Tertiary strata at Bellingham Bay have a very close relationship to species of the same geological horizon in Europe.

1861. Meek, F. B. Descriptions of new Cretaceous fossils from Vancouver and Sucia islands.—Proceedings Academy of Natural Science, Philadelphia, volume 13, pp. 314-318.

1863. Newberry, J. S. Description of fossil plants from Orcas Island, Bellingham Bay, etc.—Boston Journal of Natural History, volume 7, pp. 506-524.

1867. Blake, William P. Notes on the brown coal formation of Washington Territory and Oregon.—California Academy of Science, Proceedings, volume 3, p. 347.

A brief description of the coal measures at Bellingham Bay. They are said to dip at an angle of 70 and strike East 15 North, and to have a thickness of about two thousand feet. He reports ten workable coal seams interstratified with six or seven heavy beds of sandstones and numerous strata of bituminous shale, slate, clay, ironstone, and thin beds of sandstone. Two well preserved shells of the genus Pecten are said to have been collected. Reference is made to the occurrence of coal on the banks of the Cowlitz River.

1870. Brown, Dr. Robert. Glacial scratches near Bellingham Bay, Washington.—American Journal of Science, volume 50, p. 323.

Reference is made to the presence of fluting and grooving as evidences of glacial action at Schome near Bellingham Bay.

1871. King, Clarence. On the discovery of actual glaciers on the mountains of the Pacific slope.—American Journal of Science, volume 101, pp. 157-167.

Describes the general character of the glaciers on Mt. Rainier and states that they are the principal source of the following rivers, viz., Cowlitz, Nisqually, Puyallup and White.

1876. Meek, F. B. Descriptions and illustrations of fossils from Vancouver and Sucia islands, and other northwestern localities.—Bulletin United States Geological Survey, Territories, volume 2, pp. 351-374.

1870. Brown, Dr. Robert. On the geographical distribution and physical characteristics of the coal fields of the North Pacific Coast. Transactions Edinburgh Geological Society, volume 1, part 3, pp. 305-325.

1879. Donald, J. T. Elephant remains of southwestern part of Washington Territory.—American Journal of Science, volume 118, p. 79.

1880. Willis, Bailey. Report on the coal fields of Washington Territory.—Tenth Census of the United States, volume XV, pp. 759-771.

The coal bearing strata are described as extending up the Cowlitz valley into Puget Sound and as far as the foothills of the Olympic Mountains around the north border to Cape Flattery. Those of the Puget Sound region are referred to as the "Laramie."

"The coal measures of the Puget Sound basin consist of alternating beds of yellow and gray fine-grained sandstones and very fine gray arenaceous shales interstratified with many beds of carbonaceous shale and coal; the individual strata of sandstone and shale, from 20 to 200 feet thick, maintain the same general character wherever observed, and no well-defined horizon has been found which might serve as an index to correlate the widely-separated exposures. Leaf impressions occur in both shales and sandstones associated with unios.

"The best sections are those obtained in the Wilkeson and Green River fields, and described in detail in their proper connection, though even they are incomplete; of these one gives a minimum of 13,200 feet, with a probable maximum of 14,500 feet; a second, still less complete, measures 7,700 feet; and the third, on Green River, lies between 6,200 and 8,200 feet; and these sections do not in either case reach the limits of the coal measures, as the base of each is an anticlinal axis and the top the highest exposure, geologically speaking, beneath the volcanic flows or drift-beds. Such figures challenge confirmation, but they are the result of accurate surveys and careful observation, and are only invalidated by the possibility of undiscovered faults, of which the sections have yielded no proof under close examination.

"The fossils indicate the maintenance of fresh and brackish water conditions through this long period of deposition, implying that the general rate of this profound subsidence was the same as that of accumulation of sediments."

1881. Brockett, L. P. Our Western Empire.—San Francisco, pp. 1189-1213.

The following statement is made concerning the geology of Washington:

"The shores of the Pacific, the lower valley of the Columbia, and the great valley drained by Puget Sound, are Tertiary and Quaternary; the islands west of the Canal de Haro in the Gulf of Georgia are Cretaceous; the vicinity of Bellingham Bay is Carboniferous; the Coast Range is Eozoic; the Cascade Mountains to about 47° 40′ and the Great Plains of the Columbia River in central and eastern Washington, south of the Spokane River, are volcanic."

1888. White, C. A. On the Puget Group of Washington Territory.—American Journal of Science, third series, volume 36, pp. 443-450.

This paper deals with a collection of fossil mollusca from the Puget Group of Washington made by Prof. J. S. Newberry. The species are of brackish water origin. Two species were thought to be closely related to the Laramie of the Rocky Mountain region. Several other genera were not known to occur at any other place in North America. Mention is made of strata containing a Tejon fauna in the Duwamish valley. These strata were correlated with the upper portion of the Puget Group. The strata of the Puget Group were considered to have been deposited in estuaries.

1889. White, C. A. On invertebrate fossils from the Pacific Coast.—United States Geological Survey, Bulletin No. 51.

In this report reference is made to a collection of fossils said to come from "Fossil Bluff, Duwamish River." The region referred to is probably in the vicinity of Duwamish Station. The following is a list of the species collected: "*Cylichna costata* Gabb, *Conus hornii* Gabb, *Lunatia nuciformis* Gabb, *Leda protexta* Gabb, *Euspira alveata* Gabb, *Fusus diaboli* Gabb, *Turritella uvasana* Gabb, *Tellina* sp." The formation in this particular region was regarded as the "Tejon portion of the Chico-Tejon Series." The sedimentaries in King and Pierce counties were regarded as of estuarine origin. The brackish water fos-

sils occurring in those strata were described. To a certain extent they have a close similarity to the Laramie. There are many forms, however, which have never been observed in the Laramie and which are peculiar to the Puget Group. The term "Puget Group" is here applied to this brackish water deposit.

1891. Clark, Wm. B. Correlation Papers: Eocene.—United States Geological Survey, Bulletin No. 83, pp. 100-110.

An historical review is given concerning the literature on the Puget Group in Washington. It is suggested that the Puget Group may be in part Cretaceous and in part Eocene.

1891. White, C. A. Correlation Papers: The Cretaceous. — United States Geological Survey, Bulletin No. 82.

The upper Cretaceous or Chico formation is the coal bearing formation on the north of Vancouver Island. The same formation is known to appear in the San Juan Islands in the State of Washington.

1892. Dall, Wm. H. and Harris, G. D. Correlation Papers: Neocene.—United States Geological Survey, Bulletin 84, p. 228.

At the time this report was written very little was known concerning the occurrence of marine Miocene deposits within the state. It is stated (p. 228) "Siliceous casts of molluscan fossils have been collected at various points on Shoalwater Bay, which show a synchronism of the deposits in which they are found with both the Eocene and the Miocene clay shales of Astoria. The Astoria bed outcrops at Bruceport and elsewhere. A Pliocene deposit has been observed by Dr. Condon in this vicinity which, from its most characteristic fossil may be called the Mytillus bed. It furnished specimens of *Buccinium cyaneum*, *Mytillus condoni*, *Crepidula*, *Pecten*, and *Panopaea;* this is overlain by a Pleistocene formation, the level of which is from 30 to 40 feet above the sea." On page 271, marine Pliocene is referred to as occurring at Shoalwater Bay, 35 feet above sea level. The fossils exhibit a boreal facies.

1893. Corey, T. B. The coal fields of western Washington.—Journal Illinois Mining Institute, May, 1893, volume 11, No. 1, pp. 14-30.

This paper describes briefly some of the coal seams in Whatcom, Skagit, King, Pierce and Chehalis counties. A number of geologic cross sections are inserted.

1893. Diller, J. S. Notes on palaeontology referring to Washington.—Bulletin Geological Society of America, volume 4, p. 217.

A well preserved specimen determined by Mr. Stanton to be *Baculites* was given to Mr. Diller by Mr. W. P. Guye. It is said to have come from Snoqualmie River, three miles below the falls. Mr. Diller states: "It shows the presence of the Chico at that point. The rock is unaltered and lies between the Puget Group and the metamorphics." Careful areal geological studies have been made in that region and no strata have been found which could be assigned to the Cretaceous. It was undoubtedly derived as a fragment from the glacial drift which in that region heavily veneers the country.

1894. Diller, J. S. Tertiary revolution in the topography of the Pacific Coast.—Eighth Annual Report, United States Geological Survey. (Powell), part 2, pp. 401-434, 8 plates, 4 figures.

1895. Diller, J. S. A geological reconnaissance in Northwestern Oregon.—United States Geological Survey, 17th Annual Report, part 1, pp. 441-520.

The paper discusses the geology of northwestern Oregon. Notes are given concerning the geology on the north shore of Columbia River across from Astoria. Reference is made to the occurrence of the very lowest Oligocene strata at Knappton on the Washington side of Columbia River. The raised beach at Ilwaco in Washington is described. A drawing is added to illustrate the unconformity between the older Oligocene and the overlying Pleistocene. He states:

"At Ilwaco, on the north bank of the Columbia near its mouth, is an exposure of which a sketch is shown in figure 8. The upturned edges of the Astoria shales make the mass of the hill, and these shales are unconformably overlain about 30 feet above sea level by a series of gravel, sand, and clay layers 14 feet thick. The material in these layers is incoherent and contains occasional fresh fragments of shells belonging to species

yet living on the coast. Near the middle of the deposit is a dark seam of vegetal matter, and the character of the stratification is such as to indicate that the deposit is waterlaid and not of eolian origin.

"At the base of the hill the upturned edges of the shales have been cut off to an even surface by the waves, and this wave-cut terrace extends more than 100 yards toward the river. The top of the shales, in the hill immediately beneath the Pleistocene layer is planed off in the same way, and it is evident that when this was accomplished the shale in the hill top was then at the sea level and the waves rolled over it as they now roll over the lower wave-cut terrace to reach the beach.

"The Pleistocene capping of the hill was laid down when the ancient wave-cut terrace was below the sea level deep enough to receive the deposits we now find there. Since then, of course, it has been raised to its present elevation by a general, perhaps more or less unequal, uplifting of the land along the coast."

Mr. Diller's views concerning the Pleistocene history of Northwestern Oregon are of particular interest insomuch as it must apply in part at least to Southwestern Washington. Extensive nearly horizontally bedded sands and clays rest unconformably upon older strata up to elevations above 600 feet. Remnants of peneplains are recognized up to elevations of 2000 feet, indicating that all of Northwestern Oregon has been submerged perhaps that amount. A great sound is thought to have existed, perhaps similar to Puget Sound. Afterwards the region was again uplifted to an elevation somewhat higher than at present. The most recent movement was a subsidence sufficient to partially drown the lower Columbia and Willamette river valleys, allowing the tide to extend up a considerable distance above their mouths.

1896. Gilman, S. C. Olympic country. National Geographic Magazine. volume 7, pp. 133-141.

The paper deals primarily with explorations carried on in the Olympics. The general topographic features are described and reference is made to the occurrence of sandstones and shales in the bluffs at the mouth of Queniult River. A map of the Olympic Peninsula accompanies the report.

1896. Stanton, Timothy William. Contributions to the Cretaceous paleontology of the Pacific Coast: the fauna of the Knoxville beds.—United States Geological Survey, Bulletin 133, 132 pages, 20 plates.

The following reference is made concerning the occurrence of Knoxville strata in the State of Washington: "The presence of Knoxville beds in Washington is inferred from the occurrence of boulders containing *Aucella crassicollis* near Seattle and Tacoma and also from the fact that *Aucella* beds are well developed in British Columbia immediately north of Washington." The facts are that these boulders are of glacial origin and may have been brought down from British Columbia by glaciers.

1896. Willis, Bailey. Geology of the Cascade Mountains.—Johns Hopkins University Circular, volume 15, p. 90.

Mr. Willis states:

"In the Cretaceous period Puget Sound and adjacent areas of Washington and Oregon of indeterminable extent were beneath a sea in which limestone was the principal formation. It is probable that toward the north or northeast in northern Washington and British Columbia, there was a low land area consisting largely of granitic and metamorphosed crystalline rocks. There gradually ensued a change by which Puget Sound and the area where the southern Cascades now extend from the 48th parallel southward through Oregon became an extensive estuary, in whose waters deposits of sand and mud were laid down, and around whose changing shores there were many marshy lagoons in which a rank vegetation flourished. The conditions of estuarine deposition, which perhaps can be best exemplified by pointing to our southern Atlantic coast, endured throughout Eocene and Miocene times, and we know that in the Miocene the climate was tropical and the place of the Cascade Range was a swampy lowland near sea level. The thickness of sandstones, shales, and coal beds of the Puget Group is 7,000 to 12,000 feet or more."

1897. Dall, W. H. A table of the North American Tertiary horizons correlated with one another and with those of western Europe, with annotations.—United States Geological Survey, 18th Annual Report, Part 2, pp. 323-349.

In this paper the various Tertiary formations on the Pacific coast are briefly described and correlated with one another. He

states concerning the Puget Group of Washington: "The conditions continued through the Eocene and possibly into Miocene time. If so, the Puget Group may eventually be differentiated into several members."

1897. Kimball, James P. Physiographic geology of the Puget Sound basin.—American Geologist, volume 19, pp. 225-237, 304-322, plates 12 and 19.

In this paper numerous outcrops of pre-Pleistocene strata occurring at various points in the Puget Sound basin are described.

1897. Smith, George Otis. Rocks of Mount Rainier.—United States Geological Survey, 18th Annual Report, part 2, pp. 416-423.

Mr. Smith states:

"The volcanic rocks of Mount Rainier include both lavas and pyroclastics. The breccias, agglomerates, and tuffs, although of striking appearance, are, perhaps, less important elements in the construction of the composite cone.

"The lavas vary much in color and texture, but these megascopic differences are referable rather to the degree of crystallization of the magma than to its chemical character. The variation in the chemical composition of the lavas expresses itself in mineralogical differences, and thus four rock types are distinguished—hypersthene-andesite, pyroxene-andesite, augite-andesite, and basalt. The distribution of these types indicates a radial arrangement of lava streams, and hypersthene-andesite is the more abundant variety of lava.

"Granite is exposed on the slopes of Rainier where erosion has cut away the overlying lava, and it is plain that the volcanic cone rests upon an elevated platform of older rock, approximately 8,000 feet above sea level."

1897. Willis, Bailey. Glaciation in the Puget Sound region.—American Geologist, volume 19, pp. 144-145.

1897. Willis, Bailey. Stratigraphy and structure of the Puget group.—Bulletin Geological Society of America, volume 9, pp. 2-6.

Abstract of a paper presented to the Society August 10, 1897. A description is given of the coal bearing formations in King and Pierce counties. He states: "They are prevailingly sandstones of variable composition, texture and color, thinly interbedded, and a typical arkose consisting of slightly washed

Summit of Cascade Range Showing Characteristic Topography.

granitic minerals, to siliceous clays. Beds of concentrated quartz sands or conglomerates have not been observed. Carbonaceous materials are generally present as fragments of plants, as vegetal ooze in greater or less proportion to the other constituents and as distinct coal beds. In color they are, when fresh, generally bluish gray, shading to brownish black. They weather to buff tints, which are usually dull. Most prominent among the rocks associated with the Puget Group are eruptives of Tertiary or later age. They occur as dikes and flows in various forms of intruded and extruded igneous rocks. The measured sections of the Puget series exhibit total thicknesses of 5,800 feet on Green River, 5,500 feet on South Prairie Creek, and 5,480 feet in Carbon River canyon. None of these measures are complete. In each instance the lowest stratum is of the Eocene outcropping on an anticline and the highest is the limit of exposure where the rocks pass under later formations. The strata of the Puget Series were deposited upon the slowly subsiding bottom of the geosyncline between the axes of the present Cascade and Olympic ranges. As strata of similar composition and age are involved in the mass of the Cascade Range, and probably also of the Olympics, the uplift of these mountains was to a greater or lesser extent accomplished after the Puget Epoch." These strata have been folded. In general the axes of these folds trend north and south parallel to the axis of the antecedent geosyncline, but there are evidences in local structures which show that the forces of compression were exerted also at right angles to the greater pressure.

1898. Lawson, Andrew C. Note on the Chehalis sandstone. American Geologist, volume 13, pp. 436-437.

Note is made of some fossil bearing sandstones in the hill at Chehalis, Washington. The rock "is a sandstone of variable character. For the most part it is soft and friable. It is generally clayey and its color varies from bluish gray to yellowish, according to the stage of oxidation." Fossils collected were determined by Mr. T. W. Stanton as *Solen*, *Leda*, *Tellina*, *Venus*,

Fusus, Dentalium and others. They are of marine origin and the strata were considered to be of "Eocene or Miocene age."

1898. Merriam, J. C. Note on two tertiary faunas from the rocks of the southern coast of Vancouver Island.—University of California, Bulletin, Dept. of Geology, volume 2, No. 3, pp. 101-108.

This paper deals with two collections of marine invertebrate fossils from the south coast of Vancouver Island. One of these is from Carmanah Point and the other from the vicinity of Sooke Bay. Altogether twenty-four species were collected at Carmanah Point. He states: "The fauna of the Carmanah Point beds seems on the whole to be the same as that of Conrad's Astoria Miocene, excluding, however, the lower portion of the latter series, which has been supposed to be of Eocene age." Of the fauna collected at Sooke fifty-five per cent are extinct. Eight or nine species are living. He states: "Comparing the Sooke fauna with that of well-known Tertiary and post-Tertiary horizons on the Pacific Coast, we find that six or seven of the species are known from the Miocene and about an equal number from the Pliocene, nine species are found in the Quaternary and Recent, and seven or eight are not known to occur elsewhere, either recent or fossil." Dr. Merriam also says: "The evidence at our command indicates that the Sooke beds are of middle Neocene age, and that the time of their deposition was considerably later than that of the Carmanah Point beds."

1898. Russell, I. C. A preliminary paper on the Geology of the Cascade Mountains in Northern Washington.—United States Geological Survey, 20th Annual Report, pt. 2, pp. 83-210.

This report deals chiefly with the geology of the Cascade Mountains proper. A series of old metamorphic formations consisting of slates and schists of unknown age are intruded by granite. The Cretaceous is recognized in the extreme northern portion of the Cascades and is locally referred to as the Similkameen and Winthrop formations. The Tertiary formations which are described are confined to the eastern side of the Cascades. They consist of the Swauk, Roslyn, Ellensburg and Columbia River lava. In late Tertiary times the Cascade Mountains were reduced to a peneplain.

1898. Willis, Bailey. Some coal fields of Puget Sound.—United States Geological Survey, Eighteenth Annual Report, part 3, pp. 399-436, plates 52-68, figures 26-31.

In this report a detailed description of the geology of the coal bearing formations of Pierce and King counties is presented. Special consideration is given to the geologic structure. The preceding paper which was presented as an abstract covers the principal points in this. (1897. Willis, Bailey. Stratigraphy and structure of the Puget group.)

1899. Willis, Bailey, and Smith, George Otis. Tacoma Folio.—United States Geological Survey, Geologic Atlas, Folio No. 54.

This report describes the geology of an area involving parts of King and parts of Pierce County. The oldest formations are of Eocene age and are represented by the Puget Group. The Puget formation in this area is described as consisting "of interbedded sandstones, shales, and coal beds aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture and color, and are frequently cross stratified. Their composition ranges from a typical arkose consisting of slightly washed granitic minerals to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. In general the strata are similar and are similarly interbedded from top to bottom. The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron and generally more or less carbonaceous matter which varies in character from finely divided organic material to large leaves and stems. They accordingly range in color from rather light gray and blue to black. The lighter tints weather out brown through oxidation of the iron. The proportion of coal beds is extraordinary. Carefully measured sections show that the Puget formation contains more than 125 beds. The valuable coal is found in the lower 3,000 feet of the formation. The physical history which is recorded in the Puget formation is one of persistent but frequently interrupted subsidence of the area within which the sediments were deposited. Throughout these changes the

waters appear to have remained fresh or brackish. The fossils other than plants are prevailingly unios or other fresh water forms."

The flora is known to contain over 100 species, a very large number of which are new. The plant remains in the lower beds give evidence of a tropical climate while those in the upper are more closely related to those of the present day.

"The condition of subsidence which characterized the Puget Sound Basin during the Eocene period continued into the next, the Neocene. There is apparently no interruption or change in the sedimentary sequence to mark the transition, but plants collected from the upper part of the Puget formation differ from those taken from lower portions, and are of Neocene types.

"In the northern Duwamish Valley, in the vicinity of Steels, is an isolated area of brown sandstone containing fossil plants which are younger than any collected from the recognized Puget formation, and which may belong to a later epoch of the Neocene period. A little farther northwest in the same vicinity are outcrops of green sand in which occur marine fossils of early Neocene (Miocene) age."

1899. Diller, J. S. Latest volcanic eruption on the Pacific Coast.—Science, new series, volume 9, pp. 639-640.

Certain evidence is presented to show that Mt. St. Helens and Mt. Baker were in eruption during the early part of the 19th century.

1902. Landes, Henry. Coal deposits of Washington.—Washington Geological Survey, volume 1, Annual Report for 1901, pp. 257-281.

This report describes the coal bearing formations of the Puget Sound and Cowlitz Basin regions. The strata were believed to have been deposited under estuarine conditions during the Eocene.

1902. Landes, Henry. An outline of the geology of Washington.—Washington Geological Survey, volume 1, Annual Report for 1901, pp. 11-35.

In this report the state is divided into five topographic provinces. A preliminary geological map of the state is inserted, showing the areal distribution of formations as known at that

time. The coal measures of Puget Sound are recognized as of Eocene age. The sedimentaries in Kitsap County are referred to as Miocene, as well as the belt bordering the south side of the Strait of Juan de Fuca and the larger part of southwestern Washington.

1902. Landes, Henry, and Ruddy, C. A. Coal deposits of Washington. —Washington Geological Survey, volume 2, pp. 167-275.

A more detailed discussion is entered into concerning the coal bearing formations than in the previous report. The following generalized statement is made:

"The coal measures of Washington belong to the early part of the Tertiary period or the Eocene epoch. In only a very few instances has the base of the coal measures been found. In the coal fields of Whatcom and Skagit counties the lowest strata of the coal measures lie upon a metamorphic rock, a mica schist of unknown age. At the Blue Canyon and Cokedale mines the largest coal seams lie but a few inches or at the most, but a few feet, above the schists. In general in the different fields the principal seams of coal lie well toward the bottom of the coal series and hence belong to the earlier portion of the epoch. In Washington, during Eocene time, the shore line was somewhere in the vicinity of the eastern border of Puget Sound, and extending southward beyond the present boundary of the state. The Olympic Mountains formed a large island immediately off the coast. The region of the Cascade Mountains was in general one of low relief.

In the northern portion of the state, however, the Cascades were doubtless of considerable height and the streams flowing from them possessed of great strength, as shown by the coarse character of the sediments deposited at that time. The hills were composed of granite rocks as shown by the character of the sediments derived from them. The fossil contents and character of the sediments of the coal fields of Roslyn-Clealum and those of Whatcom and Skagit counties show that these fields represent lake deposits. In the case of the Whatcom coal field the sediments reach an approximate thickness of 20,000 feet and are made up of massive sandstones and coarse conglomerates. In the remaining coal fields as far as known, the coal swamps were in estuaries along the shore where brackish water conditions prevailed."

1903. Smith, George Otis. Geology and Physiography of Central Washington.—United States Geological Survey, Professional Paper No. 19, pp. 1-44.

The area involved in this paper lies in the east central part of the Cascade Mountains. The deformational movements are of importance because of their possible influence on the western side of the mountains. Concerning the geologic history of central Washington, it is stated:

"The oldest rocks, probably of Paleozoic age, furnish a record of sedimentation and volcanism, but this record has been greatly obscured by the altered condition of these rocks. This metamorphism in turn tells of the orogenic movements to which the rocks have been subjected and of the action of intrusive magmas.

"The great intrusions of peridotite and granodiorite probably belong to the Mesozoic, and were events of the first importance in the history of this portion of the Cascade Range. The period of erosion subsequent to these intrusions was of sufficient length to allow these deep-seated bodies to be uncovered and deeply dissected.

"From these eroded older rocks was derived the material for the Eocene sediments, and the process of sedimentation appears to have been a rapid one within this area, since several thousand feet of granitic sands and other sediments were deposited in early Eocene time, before uplift again inaugurated erosive activity. Then began the first basaltic eruptions, the forerunners of the greater volcanism of the Miocene. This volcanic activity was succeeded by the quieter processes of sedimentation, by which the Roslyn sandstone was deposited in middle Eocene time. Somewhat later, in an adjacent area, the deposition of the Manastash sediments took place, and the Eocene period closed with the uplift and folding of all of these Eocene formations.

"Erosion continued well into the Miocene within this area, but ceased with the beginning of the great eruption of basalt, the many flows of which covered the greater part of central Washington like a molten sea. Immediately succeeding this epoch of volcanism came the deposition of the Ellensburg formation, thick deposits of stream sands and gravels, brought down from a volcanic area to the west.

"Mountain building movements followed this sedimentation of the later Miocene, and again erosion began to cut away what had been uplifted."

During the Neocene the region was extensively peneplained. Concerning its uplift later, he states:

"The ultimate deduction is that, whatever the relative proportion of antecedent and consequent character in the drainage system, the main divide for the greater portion of its length in this area neither coincides with nor parallels the axes of most marked deformation of the preexistent surface. The uplift to which the Cascade Range owes its origin was not simple in type but complex, and within this area, can be resolved into three well defined upwarps, which, moreover, are transverse to the main trend or major axis of the range considered over the large area to the north."

1905. Arnold, Ralph. Gold placers of the coast of Washington.—United States Geological Survey, Bulletin No. 260, pp. 154-157.

Certain bluffs of Pleistocene sands and gravels occurring along the ocean south from Cape Flattery contain small amounts of placer gold. These Pleistocene deposits rest upon the upturned edges of the older shales and sandstones.

1905. Arnold, Ralph. Coal in Clallam County, Washington.—United States Geological Survey, Bulletin No. 260, pp. 413-421.

This report describes the coal-bearing Miocene formations east of Clallam Bay, Washington. Mention is made of the Eocene basalts in the vicinity of Port Crescent and also of the pre-Oligocene formations south of Cape Flattery. The Oligocene-Miocene strata occurring along the Strait of Juan de Fuca are described as well as their thickness, composition and structure. Special mention is made of the coal deposits found in these strata. The more important geologic results are to be found in Mr. Arnold's paper on the Olympic Peninsula published the following year.

1905. Diller, J. S. Coal in Washington, near Portland.—United States Geological Survey, Bulletin No. 260, pp. 411-412.

Reference is made to the occurrence of coal on Coal Creek in Cowlitz County, 12 miles west of Kelso. The coal seam is 6

feet to 7 feet thick with two small partings of sand. It is overlain by soft sandstone. He states: "The bed of coal is interstratified with a lot of shales and shaly sandstones well exposed along Coal Creek near the mine. The strike of these beds near the mine is northwest-southeast with a dip of about 15 S. W. There are igneous rocks cutting the coal bearing beds in that region and the strata are faulted locally. Marine shells occur in the strata 3 feet above the coal. Among them is the ribbed *Venericardia planicosta*, which is characteristic of the Eocene. The coal is essentially of the same age as that farther north in Washington."

1906. Arnold, Ralph. Geological reconnaissance of the coast of the Olympic Peninsula, Washington.—Geological Society of America, Bulletin 17, pp. 451-468, 4 plates, 4 figures.

This paper contains a description of the topographic and physical features of the Olympic Mountains, as well as the geologic formations and their structure. The following statement is made concerning the geologic formations:

"The formations involved in the geology of the coastal region of the Olympic peninsula include serpentine, old diabase or greenstone, metamorphosed sandstone and quartzite, probably of Jurassic age; 6,000 feet of gray sandstone with minor quantities of carbonaceous shales, supposed to represent the lower part of the Puget group and of Cretaceous age; 1,200 feet of basalt and conglomerate, sandstone and shale; 2,260 feet of Pliocene conglomerate, clay and gravel. In addition to this the Oligocene-Miocene breccia contains large quantities of angular fragments of hard black slate, indicating a probable widespread formation of this type of rock somewhere in the general region. Nothing is known of the age of the slate, except that it is pre-Oligocene."

Five recognizable faunas are described as occurring in the Clallam formation along the Strait of Juan de Fuca: 1st, Lowest clay shale (Oligocene); 2nd, "above the clay-shale horizon is a series of medium bedded to fine massive sandstones in which are found a fauna apparently transitional from the clay-shales to the coarse sandstones"; 3rd, a horizon of Miocene sandstone occurring east of Clallam Bay; 4th, the fourth fauna is found

near the top of the Clallam formation in sandstone layers interbedded with conglomerates; 5th, "The fifth fauna of the Oligocene-Miocene is that found at the mouth of the Sekiu River in beds the equivalent of the uppermost strata of the Cape Flattery section."

The Pliocene is described as occurring in a synclinal trough at the mouth of Queniult River. The term Queniult formation is applied to these strata. The following statement is made concerning the geologic structure:

"As indicated by the exposures along the coast, the structural lines in the region from Port Angeles to Gettysburg average approximately parallel to the trend of the Olympics, north 70° west, south 70° east; those in the Gettysburg-Clallam Bay territory almost perpendicular to this, or a little east of north, and those in the Clallam Bay-Cape Flattery stretch north 30° west, south 30° east, or again parallel with the ridges which extend along the coast in this region. A syncline, with its southern limb resting against the sandstones south of Lake Crescent and its northern one truncated by the waters of the strait of Fuca, is the major structural feature of the Port Crescent-Gettysburg region. From Gettysburg westward to the mouth of the Pysht River the structural features are not pronounced, the rocks in general, however, having a westward dip. A rather broad syncline, with its axis extending in a northeasterly-southwesterly direction, occupies most of the territory between the Pysht River and Clallam Bay. This syncline is complicated in its southeastern portion by sharp local folding and some faulting. The region between Clallam Bay and Cape Flattery is formed by a great northeast-dipping monocline, the beds of which appear to have a total thickness of over 15,000 feet.

"South of the Clallam Bay-Cape Flattery monocline is the western extension of the axis of the Olympic Mountains. The structure in the region about this line of disturbance is quite complex, but as one goes away from it toward the south the structure becomes simpler. Several determinable folds with northwest-southeast axes were noted along the coast between the Ozette and Hoh rivers, and in the vicinity of the mouth of the Queniult there is a very prominent syncline developed in the Pliocene, with its axis parallel to those just mentioned.

"A great uplift in the Olympic Peninsula region appears to have taken place at or near the close of the Miocene epoch and still another lesser one during the late Pliocene. That orogenic movements are still taking place, or have occurred since the deposition of the Pleistocene, is evidenced by the very gently folded and tilted clays, sands, and gravels in the vicinity of Port Angeles."

1906. Arnold, Ralph. The Tertiary and Quaternary pectens of California.—United States Geological Survey, Professional Paper No. 47.

This paper consists primarily of descriptions of Pectens occurring on the Pacific Coast. The majority of the forms are from California, although several new species are from the Eocene and Miocene of Washington. Lists of other associated species occurring with the Pectens are given. Among the more important localities in Washington are Little Falls, where the Eocene strata occur, and the Oligocene-Miocene along the north coast of Clallam County.

1906. Smith, Geo. Otis, and Calkins, Frank C. Description of the Snoqualmie Quadrangle.—United States Geological Survey, Geologic Atlas, Folio No. 139, 14 pages, 3 maps, 1 columnar section.

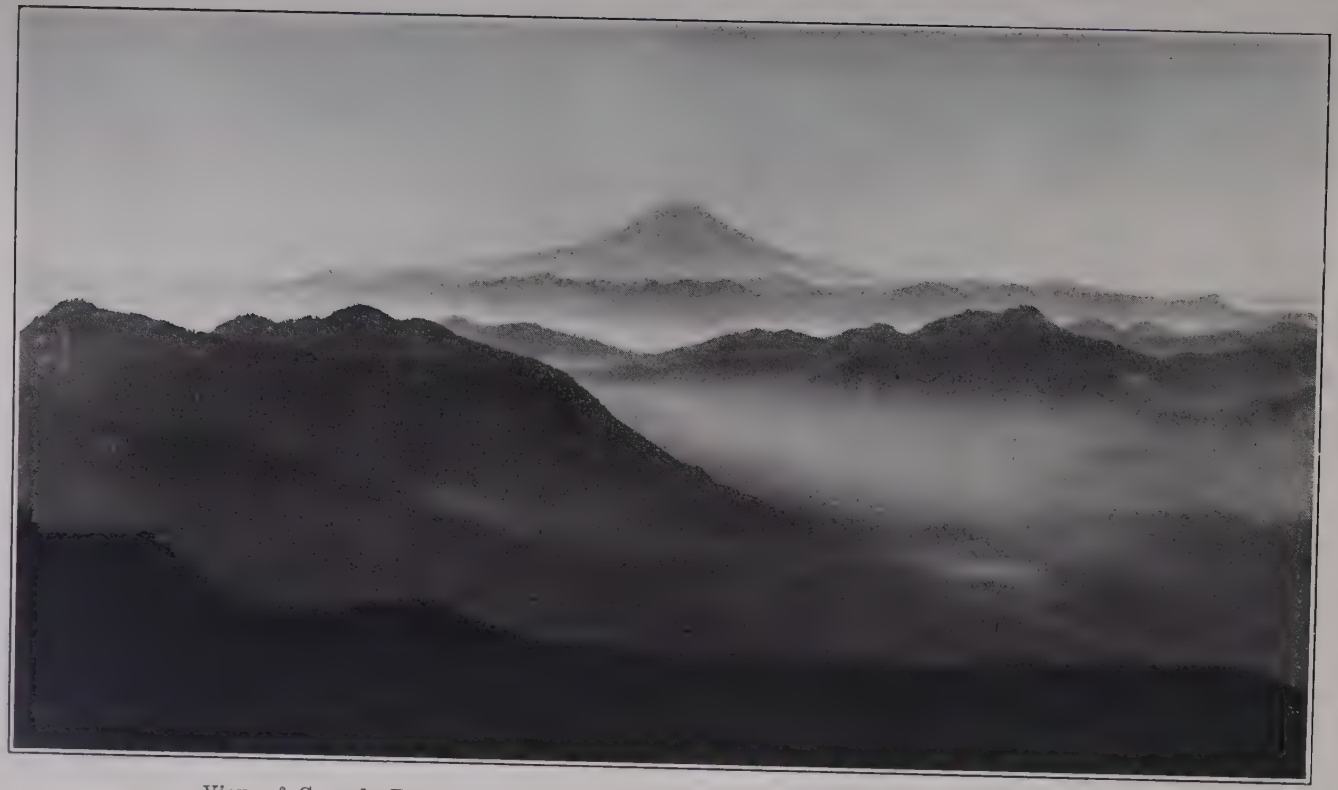
The area involved in this report is confined to the central part of the Cascade Range. The western portion of the quadrangle is largely covered with the Keechelus volcanic series which is of importance because of its probable extension westward to the Puget Sound region.

1907. Reagan, Albert B. Some geological studies of northwestern Washington and adjacent British territory.—Kansas Academy of Science, Transactions, volume 20, part 2, pp. 95-121.

The larger part of the area involved is covered with glacial drift. The pre-Glacial sediments at Bellingham are mapped as Eocene as are the metamorphics on Lummi Island. Basalts are said to outcrop in places just north of the international boundary line.

1907. Weaver, Charles E. Notes on the bed-rock geology of the Olympic Peninsula.—Mountaineer, pp. 58-64.

This paper was written from a popular standpoint. It records some geological data collected on a trip up the Elwha



View of Cascade Range, Taken From Mt. Rainier, Looking South Toward Mt. Adams.

Basin on the way to Mt. Olympus. The central portion of the Olympic Range is composed of slates and quartzites possessing an enormous thickness and having a general trend of North 60° West.

1909. Arnold, Ralph. Environment of the Tertiary faunas of the Pacific Coast of the United States.—Journal of Geology, volume 17, No. 6, pp. 509-533.

The general relations of the Tertiary on the Pacific Coast are discussed, including that of Washington. He states: "Immediately preceding the Eocene period practically all of Washington, all of Oregon, excepting a small area along the southern border, the Sierra and desert region, and certain portions of the coastal belt of California were dry land." During the Eocene continuous oscillations of the sea floor were taking place, allowing the deposition of alternating deposits of estuarine and marine origin. In the Oligocene, strata "consisting largely of sandy to clayey shales and carrying a characteristic marine fauna are found at many localities throughout Puget Sound region. Wherever their relations are known these beds lie conformably with the Eocene below and lower Miocene above; they therefore mark areas of persistent subsidence."

1909. Arnold, Ralph. Notes on some rocks from the Sawtooth Range of the Olympic Mountains, Washington.—American Journal of Science, fourth series, volume 28, pp. 9-14.

Describes some rock specimens collected from the Olympic Mountains west of Lake Cushman. They are quartzites and associated metamorphics of pre-Tertiary age.

1909. Dall, William Healey. The Miocene of Astoria and Coos Bay, Oregon.—Professional Paper No. 59, U. S. Geological Survey.

This paper is primarily a description of the Tertiary fauna from Coos Bay and Astoria. A number of new species from the Tertiary of Washington are described. The discussion of the geological conditions at Astoria is of especial interest as the fossils are closely related to similar forms in Washington. He states:

"No proper Eocene is exposed at Astoria, but the rocks may occur below the water level. The *Aturia* bed, of Oligocene age, in which *Aturia angustata*, *Miopleiona indurata*, *Marcia oregonensis*, *Trophosycon oregonensis*, and *Scapharca devincta* appear to be characteristic species, as already explained, is no longer accessible, its outcrop having been close to the water's edge under the most elevated part of the high bluff behind the town, which is strung along on a narrow talus or built out on piles over the river, there being hardly any level land between the bluffs and the water. At Smith's Point, west of the town, the shales are very low, the vertical face not exceeding 15 feet. They dip about 16° in a southeasterly direction and are composed of thin layers of chiefly bluish-gray shale with numerous fractures lined with peroxide of iron which develop more numerously as the surface dries, while the iron causes the face to weather into a brownish color. Most of the layers contain a little sand, but some do not show any. The fluctuations seem to succeed each other with a certain regularity.

"Here and there a little gravel is mixed in one of the layers and in these gravelly layers are also small fragments of bivalve shells, the most perfect and numerous being valves of Pecten *(Pseudamusium) peckhami* Gabb, *Acila conradi* Meek, and fragments of a species of *Terebratalia*.

"At some places in the upper layers of the shale the clayey parts form along a bedding plane lines of concretions, partly fossiliferous and containing most commonly specimens of *Macoma calcarea* in a bad state of preservation.

"Above the shales at this point is a bed 8 to 20 feet in thickness of a yellowish clayey sand with irregular, mostly rounded fragments of a harder sandstone, maculated with peroxide of iron, with a few traces of marine fossils, and more or less gravel not regularly bedded and penetrating into fissures in the shaly rock below, in the form of dikes. The beach in this vicinity is composed of the pebbles, nodules, and small boulders of the hard sandstone washed out of this layer mixed with a few fragments of volcanic tufa.

"Near Tongue Point, at the other end of the town, two miles away, the same beds were recognized, but the gravelly layer seemed thicker and the shale much broken up. The same beds appear to compose the bluffs between Tongue and Smith's points, though owing to the way the town is built they are difficult of access. These bluffs at their highest point, near the high-school

building, rise perhaps 150 feet. Here a fine section shows 30 to 40 feet of the shales exposed at an angle of 40° to 60°, dipping about 26° S. E., though the dip is not invariable. The yellowish sandstone gravel overlies the shales of an equal thickness and descends into them in dikes here and there. The upper margin of the shales is in places indistinguishable, the clayey and sandy layers merging into each other and being similar in color.

"It is notable that in the upper part of the shales some of the shells seem to have been fossilized in sandstone, washed out and reembedded in the clays. Between the valves or on one side of a single valve of a bivalve shell, there will be a remnant of soft coarse sandstone, while the fossil is otherwise embedded in a dark waxy clay shale.

"These sandstones and shales have much similarity to Miocene deposits occurring in various localities along the coast from California to Alaska and part of the fossils are of identical species.

"The Aturia bed and the superincumbent Astoria group occur on the north bank of the Columbia in a good many places, apparently more elevated than on the Oregon side.

"From a preliminary examination of Miocene beds examined by Ralph Arnold under my instructions at Clallam Bay, Washington, it would seem that the species agree more generally with those of Astoria; but the difficulty of correlating in the present state of our knowledge is indicated by the fact that no trace of Sooke Miocene fauna, profusely developed on the Vancouver Island shore of Juna de Fuca Strait has yet been found after careful search on the opposite coast of Washington."

1909. Darton, Nelson Horatio. Structural materials in parts of Oregon and Washington.—United States Geological Survey, Bulletin No. 387.

In this report brief descriptions are given of those rocks which are of importance as structural materials. In the vicinity of Portland the areal distribution of basalts are shown upon a topographic map. No age is assigned to them. They may possibly be Eocene.

1909. Reagan, Albert B. Some notes on the Olympic Peninsula, Washington.—Kansas Academy of Science, Transactions, volume 22, pp. 131-238.

This paper records the results of some geologic studies along the shore of the Strait of Juan de Fuca in Clallam County and

in the valleys of the Bogachiel and Soleduck rivers. Collections of fossils were made at numerous points and from these several new species are described. The principal formations involved are the Oligocene-Miocene and some Pliocene strata outcropping near the mouth of the Bogachiel and Soleduck rivers. Many of the molluscan species in the Miocene are characteristic of strata of the same age in many parts of western Washington.

1910. Bretz, J. Harlen. Glacial lakes of Puget Sound.—Journal of Geology, volume 18, No. 5, pp. 448-458.

This paper deals exclusively with certain phases of the glacial history of the Puget Sound region. Pre-Pleistocene deposits are not discussed. During the Glacial epoch the ice field is said to have filled the Puget Sound region. As it retreated it left ponded water in front forming a large glacial lake, which was not drained off until the front of the ice sheet had passed north of the junction of Puget Sound and Strait of Juan de Fuca.

1911. Bretz, J. Harlen. Terminal moraine of the Puget Sound glacier. —Journal of Geology, volume 19, No. 2, pp. 161-174.

This paper deals entirely with Pleistocene deposits of glacial origin in the Puget Sound basin. Mention is made of bed rock formations resting beneath the glacial deposits.

1911. Smith, E. Eggleston. Coals of the State of Washington.—United States Geological Survey, Bulletin No. 474.

This paper deals chiefly with the analyses of coals from Washington coal fields. However, record is made of stratigraphic and structural data collected at those points where coal samples were taken.

1912. Clapp, Charles H. Southern Vancouver Island.—Geological Survey of Canada, Memoir No. 13.

The area reported upon is entirely outside of the state of Washington, but the formations involved are so closely related, both structurally and physiographically, that it should be included.

The pre-Cretaceous complex has apparently had a history in common with that of the Olympics. During the Cretaceous, parts of the region were submerged, allowing deposition of Chico sediments. During the Miocene the southern coast of the island was submerged and the sediments of the Carmanah and Sooke formations deposited. During late Miocene and Pliocene the entire southeastern part of the island is believed to have been reduced to a peneplain. Late in the Pliocene or early in the Pleistocene the peneplain was uplifted and maturely dissected and then later somewhat depressed, forming the present drowned valley topography.

"On the retreat of the earliest and largest glaciers, the land stood some 200 to 400 feet lower than at present, and on the lowlands developed by the pre-Glacial erosion cycle, marine sediments were deposited, while large rivers flowing from the retreating glaciers formed extensive fluviatile and delta deposits. A second period of glaciation is recorded by the till overlying these deposits, but it was far less intense than the first period, and merely eroded portions of the stratified deposits. Soon after, or possibly before the retreat of the later glaciers, an uplift of some 200 to 400 feet took place, uplifting the stratified deposits, which have been submaturely retrograded during the present marine cycle."

1912. Evans, George Watkin. The coal fields of King County.—Washington Geological Survey, Bulletin No. 3.

In the investigation of the King County coal fields, detailed observations were taken on surface outcrops wherever possible. This information has been platted upon a map. The rocks as exposed in Green River are of Eocene age and have been divided into three groups: the Bayne, Franklin and Kummer.

1912. Weaver, Charles E. Geology and Ore deposits of the Index Mining District, Washington.—Washington Geological Survey, Bulletin No. 7.

The area involved in this report lies in the western foothills of the Cascade Mountains in Snohomish County. The formations are chiefly pre-Tertiary in age and consist of metamorphics intruded by granodiorites. They represent, however, the basement complex upon which the Tertiary of Puget Sound

rests. At Index these old formations occur at elevations ranging from five hundred to five thousand feet above sea level.

1912. Weaver, Charles E. Preliminary report on the Tertiary Palaeontology of western Washington.—Washington Geological Survey, Bulletin No. 15.

A preliminary outline is presented of the areal distribution of the pre-Tertiary and Tertiary formations in the western part of the state. The following subdivisions were made of the Tertiary:

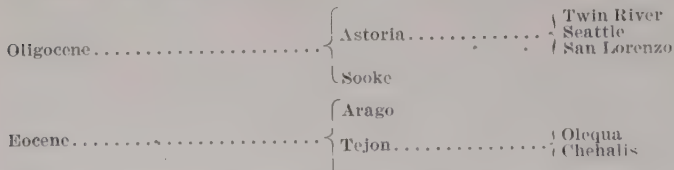
Pleistocene—			
Pliocene—wanting			
Miocene	Upper	Montesano formation	
	Lower	Chehalis formation Wahkiakum formation Blakeley formation.	
Oligocene	Lincoln formation		
Eocene	Upper	Tejon formation.. Cowlitz formation,	Puget Brackish- water group
	Lower	Wanting.	

The Cowlitz formation was regarded as provisional with the understanding that it might represent a part of the Tejon. A partial list of the marine fauna was included and eighty-four new species of invertebrates were figured and described.

1913. Arnold, Ralph, and Hannibal, Harold. The marine Tertiary Stratigraphy of the North Pacific Coast of America.—Proceedings of the American Philosophical Society, volume LII, No. 212, pp. 559-605.

This paper presents the ideas of the authors concerning the correlation of the marine Tertiary deposits of Oregon and Washington and gives a list of the fauna found in each division. The following stratigraphic column is submitted for the North Pacific Coast:

Age—	*Formation*
Pleistocene	Saanich Vashon Drift
Pliocene	Admiralty Till Elk River Merced
Miocene	Empire Monterey (Clallam)



1913. Bretz, J. Harlen. Glaciation of the Puget Sound Region.—Washington State Geological Survey, Bulletin No. 8.

This paper is confined almost entirely to a discussion of the glacial deposits and history of the Puget Sound region. Concerning the Pliocene he states:

"For this region the Pliocene was primarily a time of diastrophic movement and erosion. The Eocene and Miocene beds were domed and folded, the whole area was lifted higher than at present, and subaerial erosion developed great relief in the weak Tertiary rocks already deposited."

The following three epochs of Pleistocene glaciation are recorded as "Admiralty (glacial), Puyallup (interglacial) and Vashon (glacial)."

Concerning diastrophism during the Pleistocene, he states:

"The land was high during the Pliocene, presumably higher than at any subsequent time. At the time of the retreat of the Admiralty ice, however, the region was slightly lower than at present; marine organisms in the Admiralty sediments having been found *in situ* a few feet above present high tide. Early in the Puyallup interglacial epoch, the region was probably a thousand feet higher than now. At the maximum of Vashon glaciation outwash gravels were poured westward down the Chehalis as far as the present head of Grays Harbor, where they now lie 35 feet above tide, with stream bedding. From this we may conclude that the land had lowered from its high interglacial portion to one near that of the present."

As the Vashon began to retreat a lake developed in front to the south. After Vashon retreat opened the Strait of Juan de Fuca the waters of the lake were replaced by marine waters. From the presence of marine shells at elevations as high as 280 feet, it is thought that there was a post-glacial submergence of the Puget Sound region of that amount.

"When the submergence was 120 feet or more in excess of the present, Grays Harbor and Puget Sound were connected by tide water across the site of Lake Russell's discharge-way and the Olympic Mountains constituted an island."

After this submergence the Puget Sound region was re-elevated to approximately its "immediately post-glacial position."

1913. Collier, A. J. Coal Resources of Cowlitz River Valley, Cowlitz and Lewis counties, Washington.—Bulletin No. 531, U. S. Geological Survey, pt. 2, pp. 323-330.

This paper contains results of a brief investigation of coal resources of the southern part of the Cowlitz River valley in Washington. He states:

"Along Cowlitz River northward from its junction with the Columbia lies an area of coal land 30 miles long and 15 miles wide. Probably a large part of this area is not underlain by coal, but beds are exposed at so many places in the field that all of it is considered possible coal land. This field is probably continuous with that about Centralia and Chehalis, although for a few miles south from Chehalis no outcrops of coal have been found. The prevailing rocks are soft sandstones, which lie approximately horizontal and which locally contain beds of coal. Fossils of Eocene age are found in the sandstones. Besides the sedimentary rocks there are a great many bodies of igneous rocks, some of which are known to be of the same age as the sedimentary beds, whereas others are of later intrusion or extrusion. For example, a few miles north of Castle Rock an old lava flow, overlain by the later Eocene sediments, outcrops. Near Kelso there are several masses of rock, which cut through the sedimentary formation in the form of dikes, and on the east side the coal field is limited by later eruptive rocks, presumably of the Miocene series, which forms a large part of the Cascade Mountains farther south.

"The structure of the sedimentary rocks consists of open folds, in which the dips are low. Faults do not appear on the surface, but they have been encountered in some mines, causing abandonment. The structure in this field appears to be decidedly different from that about Chehalis and Centralia. In that field the coal beds dip as high as 70°, whereas in this field the beds nowhere dip more than 25°."

Mount Rainier Looking North From Tatoosh Range.

1913. Landes, Henry. Notes on Glacier coal field.—Pacific Mining Journal, volume 2, No. 4.

This area involved is situated in Whatcom County northeast of Bellingham and northwest of Mt. Baker. Sandstones and shales outcrop and within them seams of anthracite coal are found interbeded.

Throughout the Glacier field the strike of the formations is approximately east and west with some small local variations. The dip of the strata is almost universally to the northward, thus giving to the field as a whole a monoclinal structure. The persistency of the dip northward is something remarkable. Not only is it true between Discovery tunnel and Glacier, but as far north as Church Mountain, which is located about three miles northeast of Glacier, the same northward dip persists. How much farther to the northward of Church mountain the monoclinal structure continues is unknown at the present time. The angle of dip varies greatly throughout the field. On the steep mountain sides the amount of dip seems to be greater than that in the valleys or where the slopes are not so precipitous. It is interesting to note that the slope of the mountain and the dip of the formations are in the same direction. It is very clear that as a result the rocks near the surface have settled forward so that they have a greater apparent angle at the surface than they have at a depth below the limit of surface influence.

1914. Lupton, Charles T. Oil and Gas in the western part of the Olympic Peninsula, Washington.—U. S. Geological Survey, Bulletin 581-B, pp. 23-80.

This paper presents the results of a geological examination of the region on the western side of the Olympic Peninsula and south of the Cape Flattery axis. A record is given of numerous observations taken on the strikes and dips as well as a description of all occurrences of oil and gas.

1914. Washburn, Chester W. Reconnaissance of the Geology and Oil Deposits of Northwestern Oregon.—U. S. Geological Survey. Bulletin 590, pp. 1-111.

In this report a record is made of the occurrences of Tertiary strata in the coast ranges of northwestern Oregon and also along the north shore of Columbia River in Pacific County, Washington. The strata outcropping along the north shore of Columbia River between Megler and Fort Columbia tunnel are described as being of Eocene age on the basis of a partly worn hinge of *Venericardia planicosta.*

1915. Dickerson, R. E. Fauna of the Type Tejon: Its Relation to the Cowlitz Phase of the Tejon Group of Washington.—Proceedings of the California Academy of Sciences, Fourth Series, volume 5, No. 3, pp. 33-98, plates 1-11.

A list is given of fossils collected one and one-half miles east of the town of Vader, Lewis County, Washington, in the shales outcropping in the banks of Cowlitz River. This fauna is regarded as representing the same faunal facies of the fauna of the type Tejon of California, *i. e.*, the Rimella simplex Zone.

1915. Clark, Bruce L. The Occurrence of Oligocene in the Contra Costa Hills of Middle California.—University of California, Publ. Bull. Geol., volume 9, pp. 1, 16-21.

Studies made in the Coast Ranges of California show the Agasoma gravidum zone to be unconformable beneath the Arca montereyana zone. This unconformity is believed to be of wide extent. The faunal break between the Oligocene and Miocene in Oregon and Washington appears to be as great as in California.

1915. Weaver, C. E. The Possible Occurrence of Oil and Gas Fields in Washington.—Transactions American Institute of Mining Engineers, Bulletin No. 103, pp. 1419-1427.

A short description is given of the formations in the western part of the state and the structural conditions in their relation to the possible occurrence of oil and gas.

1916. Weaver, C. E. Tertiary Faunal Horizons of Western Washington.—University of Washington, Publ. Geol., volume 1, No. 1, pp. 1-67, plates 1-5.

The report describes several new species of Tertiary Mollusca from western Washington. A list is given of the species known to occur in the Eocene, Oligocene, and Miocene formations of Washington. The Tertiary deposits of the western part of the state are divided into five divisions on a faunal basis. The Eocene is represented by the Tejon as known in California. The Oligocene is divided into three faunal zones. The lower Miocene corresponds to the Arca montereyana zone and the upper may be the equivalent of the Empire formation of Oregon.

CHAPTER I.

TOPOGRAPHY AND DRAINAGE.

GENERAL STATEMENT.

The western half of the North American continent, embracing the entire area west of the Rocky Mountain divide as far as the Pacific Ocean, is commonly recognized as divisible into five distinct provinces, all of which have a general elongation parallel to the western margin of the continent. From east to west these provinces are generally referred to as the Rocky Mountain system; the elevated plateaus of the interior; the Sierra Nevada and Cascade ranges; the structural downfold involving the great valleys of California, the Willamette Valley of Oregon, the lower Cowlitz Valley and the Puget Sound Basin of Washington; and the Coast Ranges of California, Oregon and Washington.

With the exception of the Rocky Mountain province these extend north and south across the state of Washington. The topographic features within the state may be grouped into seven divisions: Cascade Mountains, Okanogan Highlands, Columbia Plateau, Blue Mountains, Puget Sound Basin, including the lower Cowlitz Valley, Olympic Mountains and the Coast Ranges of southwestern Washington.

The Cascade Mountains extend from the Oregon line almost due north to the Canadian boundary. The northern portion is approximately 100 miles in width. To the south the range gradually narrows and in the central part has a width of only 75 miles. The crest line from north to south is somewhat sinuous in outline due to the differential resistance to erosion and difference in erosional power of streams heading on the eastern and western slopes. The general surface of the Cascades when viewed from any of the higher peaks gives the impression of a deeply dissected, slightly undulating plain. The summits of the ridges seem to constitute the remnants of a former peneplain the surface of which averages 6,000 feet above sea level.

Located upon this strongly dissected plateau surface are five high volcanic cones, the remnants of former active volcanoes. Mt. Baker in Whatcom County, attaining an elevation of 10,750 feet, is situated forty miles west of the main divide of the Cascades. About 70 miles to the southeast of Baker, in eastern Snohomish County, is Glacier Peak, having an elevation of 10,436 feet, and situated ten miles west of the summit of the range. A little distance south of the middle of the Cascades, in southeastern Pierce County is Mt. Rainier, the highest peak within the state, attaining an elevation of 14,408 feet. It is situated twelve miles west of the summit of the range. Mt. Adams, 12,307 feet high, is located 35 miles north of Columbia River on the main divide of the Cascades. Thirty miles due west of Mt. Adams is Mt. St. Helens, with an elevation of 9,750 feet. The slopes of the cones are the gathering grounds of permanent snow fields or glaciers, feeding the streams issuing from their base, so that they have as a rule been partly dissected by erosion. The topography of the northern portion of the range is much more rugged than the southern part. The western slope of the Cascades is a maturely dissected mass of strong relief modified by glacial erosion. At the heads of the valleys on both sides of the summit are glacial amphitheatres or cirques many of which contain small alpine glaciers or rock-rimmed lakes.

The Okanogan Highlands are situated in the northeastern portion of the state and extend from the northern Cascades easterly to Idaho. They terminate abruptly on the south along Columbia and Spokane rivers and extend on the north across the international line into the great interior plateaus of British Columbia. These mountains are much less rugged than the Cascades and rise only to elevations of 6,000 feet or less.

The Columbia Plateau lies east of Columbia River and south of the Okanogan Highlands. It consists of several plains grading into one another which range in elevation from 500 to 2,000 feet. It is crossed by numerous anticlinal ridges and its surface is scarred by several abandoned stream channels.

The Olympic Mountains occupy the northwestern portion of the state and when viewed from an elevation suggest an uplifted and deeply dissected peneplain at an average elevation of 5,000 feet. The surface of this plain appears as an axial upwarp with a low angle slope to the southwest and northeast. Rising above the surface are numerous residual monadnocks such as Mt. Olympus, Mt. Angeles, Mt. Eleanor, Mt. Constance, The Brothers and Mt. Church. These mountains attain elevations up to 8,250 feet. Volcanic peaks are absent from the range. The main divide of the range trends from Hood Canal in the area between Duckabush and Skokomish rivers northwesterly to Cape Flattery. The main stream valleys bear away from the axis of the range to the northeast and southwest. The sides of the valleys are bold and rugged and near their heads are small alpine glaciers and snow fields. Bordering the Olympic Mountains on the north and west is a low coastal plain averaging 600 feet in elevation and deeply covered with deposits of glacial drift, river gravels and sand. This low plain is also dissected by the streams flowing across it. The eastern slope of the mountains descend abruptly to Hood Canal while the southern side gradually merges into the low lying hills of southwestern Washington.

The Coast Ranges of southwestern Washington lie between Columbia River on the south and the Chehalis Valley on the north. They extend from the Puget Sound Basin-lower Cowlitz Valley depression westerly to the Ocean. They are composed of low-lying heavily timbered hills attaining a maximum elevation of 3,000 feet. The average elevation is approximately 500 feet. The area involved is about 5,500 square miles. The western part of this area is marked by two irregular shaped embayments namely, Grays Harbor and Willapa Harbor. One prominent range of hills with several lateral spurs extends across this area diagonally from northwestern Cowlitz County, through southwestern Lewis County, and terminates at Willapa Harbor. A second less important one trends from Chehalis northwesterly to Grays Harbor, with lateral spurs.

In the northeastern portion of this province, in Thurston and southeastern Grays Harbor counties, there is a dome shaped group of hills, composed almost entirely of andesitic lavas, known as the Black Hills. They attain an elevation of 2,000 feet and structurally constitute a spur trending southeasterly from the Olympic Mountains. From the standpoint of origin it connects with the spur of the Cascades between Nisqually and Cowlitz rivers.

The Puget Sound Basin lies between the Olympic and Cascade mountains. It is limited on the north by the San Juan Archipelago and on the south by the low divide between Chehalis River and Puget Sound. The larger part of this basin is an undulating gravel surfaced plain, having an average elevation of approximately 500 feet. This plain is dissected by deep and partially submerged valleys elongated in a north and south direction. The eastern side of the basin rises gradually and merges into the western foothills of the Cascades while the western border terminates abruptly against the Olympic Mountains. The southern continuation of this province is to be found in the lower Cowlitz Valley.

Immediately north of the Puget Sound Basin there is a group of islands which constitutes part of an extensively eroded, glaciated and partially submerged mountain range connecting a spur of the Cascades with Vancouver Island. These islands are known as the San Juan Archipelago. This group, consisting of several large and many small islands, is about 50 miles in length and 25 miles in width. The islands are separated by winding marine channels of varying depth. The largest islands of the group are San Juan, Orcas and Lopez. Mt. Constitution with an elevation of 2,400 feet is the highest peak within the group.

The entire drainage of Washington is ultimately into the Pacific Ocean. The coastal margin is drained directly to the ocean but other portions of the state are drained first to several trunk channels and through these to the ocean. Three large drainage areas are recognized within the state west of the sum-

Tatoosh Range in the Cascade Mountains Showing Characteristic Topography of the Western Slope.

mit of the Cascade Mountains: Puget Sound, Columbia River and the Pacific Ocean. The largest of these is the Puget Sound area, which includes Hood Canal, Admiralty Inlet, Haro Strait, Rosario Strait and the larger part of the Strait of Juan de Fuca. These embayments receive the entire drainage from the western slope of the Cascade Mountains north of Cowlitz River including that of the Skagit, Stillaguamish, Skykomish, Snoqualmie, Cedar, Green, White and Nisqually rivers, together with numerous smaller ones. It also receives the drainage from the east and north slopes of the Olympic Peninsula. The more important streams involved are the Skokomish, Hamahama, Duckabush, Docewallips, Quilcene, Dungeness and Elwha rivers.

Nearly all of eastern Washington as well as the western slope of the Cascade Mountains south of Cowlitz River is a part of the Columbia River drainage. The more important streams within this area draining the western slope of the Cascade Mountains include the Cowlitz, Toutle, Kalama, and Lewis rivers. In addition there are several small streams in western Cowlitz and Wahkiakum counties which drain directly into the lower Columbia River.

The western border of the state from Cape Flattery southward to the mouth of Columbia River is drained through numerous small streams directly to the ocean. The more important of these streams on the Olympic Peninsula are the Soleduck, Hoh, Queets, and Queniult rivers. To the South, Grays Harbor receives the drainage from Chehalis River and all its numerous tributaries including Hoquaim, Wishkah, Wynoochee, Satsop. Skookumchuck and Newaukum rivers. Willapa Harbor and Shoalwater Bay receive the drainage from the low coastal hills of southwestern Washington. The more important of these streams are North, Nasel and Bear rivers.

The rainfall in the western portion of the state is exceedingly heavy and the amount of water carried to the ocean correspondingly great. Many of these streams have their sources in the high mountainous areas where they are fed by small glaciers or lakes which mark the sites of past glaciers. The upper por-

Olympic Range as Viewed From Seattle, Showing Low Glacial Plain of Puget Sound in the Foreground and Mt. Constance in Background.

tions of their courses are characterized by numerous small lateral streams many of which cascade down steep slopes to the main streams. In their middle stretches they have reduced their valleys to a grade with well defined floodplains in which the channels shift their position from year to year. In many instances their lower courses become sluggish and meander, resulting in the development of alluvial plains and deltas.

Numerous small lakes exist in various parts of western Washington. The majority of these owe their origin to some phase of glaciation. In the Puget Sound Basin and along the north coast of the Olympic Peninsula the majority of the lakes are associated with moraines formed during the occupation of the region by ice. Among the more important of these are lakes Washington, Sammammish, Whatcom and Crescent together with numerous smaller lakes including those on the gravel prairies south of Tacoma.

In the higher mountainous areas at the heads of the small tributaries there are commonly small rock rimmed lakes which occupy cirques or the basins of glacial amphitheatres. They usually lie in short hanging valleys and the streams issuing from them cascade to the main streams below.

On the western side of the Olympic Peninsula there are two medium sized lakes, namely: Queniult and Ozette. Lake Queniult is about five miles long and three miles wide and lies in the valley of Queniult River. Above the lake the river descends rapidly from the heart of the Olympics, while below it meanders with a fall of about 300 feet through a distance of thirty-five miles to the ocean. The lake appears to have been formed by a local damming of the river.

Lake Ozette, situated in western Clallam County on the western side of the Olympic Peninsula, is approximately eight miles long and three miles wide. It has an elevation of 50 feet above sea level and is drained directly to the ocean through Ozette River. It is situated on the gravel covered plain bordering the western side of the Olympic Mountains and owes its origin, in part at least, to glacial action.

CHAPTER II.

PRE-TERTIARY FORMATIONS.

GENERAL STATEMENT.

A large portion of the formations exposed at the surface in Western Washington is of Pleistocene age and consists of deposits of either glacial or fluviatile origin. Where the pre-Pleistocene formations are not covered, they are often so badly disintegrated and weathered that their extent, character, and structure cannot be determined. These formations may be grouped under two broad divisions. The older consists of deposits of Palaeozoic or Mesozoic age while the younger belong to the Tertiary. In this report, their description will be considered under the two broad divisions just mentioned.

It is not the object of this paper to deal very extensively with the pre-Tertiary formations. In the course of field investigations a considerable amount of detailed information concerning their extent, character, and structural relations was obtained. Insomuch as these older rocks form the basement upon which the younger formations rest and to a certain extent have influenced their mode of accumulation, it seems best to outline a few of their more essential characteristics. An old series of sediments and volcanic materials, which have been more or less metamorphosed, occur in the Olympic and Cascade mountains and also in the San Juan Islands. These range over several periods in age, but for general purposes of description are grouped together under the broad term OLD METAMORPHIC SERIES. Intrusive into these are plutonic rocks, largely of intermediate chemical composition. They are described as the INDEX GRANODIORITES. On the western side of the Olympic Mountains there is an extensive series of sandstones, shales and conglomerates which are sometimes partially metamorposed. The term HOH FORMATION has been applied to these deposits. On the north side of the San Juan Islands and in northern Whatcom County, the upper Cretaceous or Chico formation is present.

OLD METAMORPHIC SERIES.

GEOGRAPHIC DISTRIBUTION.

This series of late Palaeozoic and early Mesozoic age which have been more or less metamorphosed undoubtedly underlie nearly all of the younger formations of western Washington. In the southwestern part of the state and in the Puget Sound Basin they are covered over with later Tertiary strata. They do, however, constitute the surface rocks in three distinct geographical areas. The largest of these involves the western slope of the northern Cascades in Whatcom, Skagit, Snohomish, King and Pierce counties. To the west, almost the entire area of the San Juan Islands is composed of these metamorphic rocks. The central core of the Olympic Mountains forms the third area.

WESTERN SLOPE OF NORTHERN CASCADES.

From the summit of the northern Cascades westerly to the gravel covered plains of the Puget Sound Basin are high mountain ridges composed of quartzites, slates, schists and igneous rocks. These have been examined only in limited areas. In the valley of Skagit River north of its junction with the Sauk are exposures of partially metamorphosed sandstones interbedded with chert, breccias and slates. Along with these are lenticular bodies of crystalline limestone. The general trend of the strata is North 70° West, with a dip to the southwest, varying from 45 to vertical. Similar exposures occur northward along Baker River. In the high mountainous region between the Skagit and the north fork of Stillaguamish River and also south of Darrington, similar formations are exposed, but showing more intense metamorphism. Farther south, along the south fork of the Stillaguamish and east of Granite Falls, quartzites with interbedded metamorphosed volcanic rocks and slates are exposed. From this region they constitute a belt extending southeasterly toward Gold Bar and after crossing Skykomish River swing around to the east, past Index Mountain. In the vicinity of the town of Index these metamorphic rocks have been described as the Gunn Peak formation. In this particular region the formation consists of quartzites showing various stages of

metamorphism and interbedded with these are schists, slates, crystalline limestones and cherts together with intercalated metamorphosed lava flows.

The quartzites as a rule form units of considerable thickness. They vary in color ranging from a pure white to a dark gray. Occasionally they exhibit well defined banding but more commonly are massive. In the near vicinity of large masses of granite or diorite they show the effects of intrusive action and are sometimes twisted and gnarled in such a way that the structure is difficult to determine. In some localities they have been extensively fractured and the intersecting cracks or openings are filled with quartz in the nature of small gash veins.

Because of the great disturbances which these rocks have undergone, it is difficult to estimate their original thickness. In the area east of Index a detailed examination was made of these rocks and a minimum thickness of at least 10,000 feet was established. Three fourths of this amount is composed of quartzite and the remainder is made up of slates and schists.

In King County excellent exposures of the quartzites and schists may be seen in the valleys of the North, South and Middle forks of Snoqualmie River. These rocks have been extensively invaded by granodiorite magmas and the metamorphic rocks occur largely in the form of residuals. In many places the original shaly phases have been converted into mica schists. Both the quartzites and schists extend northeasterly into the Skykomish Quadrangle and may possibly connect with the southern extension of the Gunn Peak formation.

In western Snohomish County mica schists and quartzites extend from the Cascade Mountains and suddenly disappear beneath the alluvium of Skagit River flats. Kultus Mountain, as well as the small rock hills projecting up through the alluvium, is composed of these rock types. Westerly they become more prominent again and constitute the bulk of Fidalgo Island as well as the major portion of the San Juan Island group. They continue on westerly from the San Juan Islands into the central core of Vancouver Island.

OLYMPIC MOUNTAINS.

Quartzites and slates occur in the central part of the Olympic Mountains. Outcrops of these rocks may be seen along the canyon of Elwha River as well as along the main crest of the range leading up to Mount Olympus. Similar exposures occur at the headwaters of the Queets, Queniult and Hoh rivers. These formations may be the equivalent of those occurring in the northern Cascades or possibly younger than these. Future detailed studies will be required to determine these points.

INDEX GRANODIORITE.

AREAL DISTRIBUTION.

The Index granodiorite outcrops typically near the town of Index in Snohomish County about thirty-six miles east of Everett (Plate X). Its continuation may be traced northwesterly where it is exposed at intervals as far as Granite Falls. At the latter place it outcrops in the hills just east of the town as well as to the north in the canyon of Stillaguamish River. It has been intruded into an older series of metamorphic rocks which in the vicinity of Index have been referred to as the Gunn Peak formation. In the vicinity of Granite Falls it is also intrusive into quartzites and slates which are presumably of the same age as the Gunn Peak formation. It is quite probable that the intrusion of these magmas has in part produced metamorphism. Over a large part of the intervening country between Index and Granite Falls erosion has not as yet completely removed the overlying quartzites so as to expose the granodiorite. To the south and southwest of Index the granodiorites are unconformably overlain with a series of volcanic lavas of Tertiary age.

CHARACTER OF OUTCROPS.

The granodiorites are resistant to erosion and form high rugged mountain ridges with great talus slopes fringing their sides. They have been vigorously scoured by glacial action. Cirques and glacial lakes have been produced as a result in the higher elevated portions of the granodiorite outcrops. In the

vicinity of Granite Falls the exposures do not occur very much elevated above sea level. In the San Juan Islands small isolated patches of granodiorite may be seen intrusive into the older metamorphics. These may possibly be contemporaneous with the Index granodiorites.

PETROGRAPHIC DESCRIPTION.

The granodiorite varies much in general appearance in different parts of the country and is locally referred to by the miners as granite. The most typical phase of this rock is well exposed in the Soderberg quarry, about one mile west of Index in Snohomish County on the Great Northern Railway. The entire mass is here seen to be uniform in character in contrast to the mottled appearance which it possesses in many other parts of the district. Specimens collected from different parts of the quarry show a uniformity in texture, mineral composition and color. Megascopically the rock is holocrystalline, medium grained, dense, of a light gray color and breaks in large blocks with a slight tendency to a conchoidal fracture. When carefully examined the hand specimens are seen to be composed of light colored feldspars, hornblende, and varying amounts of biotite and quartz. Occasionally small crystals of apatite may be seen. A more detailed study of the feldspar crystals proves them to be plagioclase with only a very small amount of orthoclase. When examined microscopically these specimens are found to be composed of about 40% plagioclase, 10% orthoclase, 30% hornblende and biotite and 20% of quartz, together with occasional crystals of apatite and titanite.

CORRELATION.

The exact time during which the Index granodiorite was injected into the earth's crust cannot be absolutely determined. If the metamorphic series into which it is intruded is of Carboniferous or Triassic age, which appears most probable, it certainly must have been intruded at some time later than the Triassic. It is overlain unconformably by Tertiary volcanics.

Granodiorites of similar character occur to the southeast in the vicinity of Mt. Stuart and are found to be intrusive into an old series of metamorphic rocks of presumably Carboniferous or Triassic age. It is overlain unconformably by early Eocene sediments locally known as the Swauk formation.

Both in the Index and the Mt. Stuart region the granodiorite is younger than the metamorphic series and older than the Tertiary formations. Thus the only possible time for its intrusion was during the Jurassic or Cretaceous.

HOH FORMATION.

GEOGRAPHIC DISTRIBUTION.

Along the western coast of the Olympic peninsula in Jefferson and Clallam counties there are extensive outcrops of sedimentary rocks possessing certain characteristics differing somewhat from the other sedimentary formations within the state.

To this assemblage of strata the general term Hoh formation is applied. Areally these rocks constitute the surface outcrops over a belt approximately 60 miles in length by 15 miles in width and trending parallel to the coast. The northern limit of this belt lies on the south side of the divide extending from the central portion of the Olympics northwesterly toward Cape Flattery. It crosses the wagon road from Clallam to Forks in the vicinity of Beaver Lake and trends northwesterly in a direction approximately North 50 West and intersects the ocean shore line about two miles south of the Point of the Arches, or ten miles south of Cape Flattery. North of this line no outcrops of this formation have been recognized within the state of Washington, although it is possible that they may be represented on Vancouver Island. From the Point of the Arches southward along the ocean, exposures of the Hoh formation are almost continuously present in the bluffs. In the vicinity of Quillayute River a small local area of the Montesano formation of Upper Miocene age is found resting upon the Hoh formation. With this exception the latter continues predominately southward to a point three miles below the mouth of Queets River. Here another small area of the Montesano formation is found

resting upon the Hoh, or possibly faulted down into it. Southward from Raft River for a distance of three miles the Hoh formation is exposed along the beach and then to the south is again covered with the Miocene formations. At a point about one and one-half miles north of Cape Elizabeth, in the cliff along the ocean, outcrops of the Hoh formation are exposed for a distance of about one thousand feet. Apparently here they have been brought to the surface by faulting. This fault has caused the Hoh strata to appear in the south bank of Queniult River about four miles above its mouth in Section 6, Township 21 North, Range 12 West. South of Queniult River no outcrops are known which may be definitely assigned to the Hoh formation with a possible exception of some sandstones outcropping at the water's edge near the mouth of Copalis River. If they are again found to reappear southward it must be at some point in the coast ranges of Oregon.

The areal extent of the Hoh formation easterly into the Olympic Mountains has not been definitely determined. Examinations have been made of the rock exposures along the Queets, Hoh, and Soleduck rivers for a distance of over twenty miles from the ocean and the only formation encountered was the Hoh. From the close resemblance of certain strata outcropping along the course of Elwha River and the headwaters of the Queets and Queniult rivers in the vicinity of Mt. Olympus, it is possible that the Hoh formation extends into the heart of the Olympic range.

CHARACTER OF OUTCROPS.

The most important topographic feature of the western side of the Olympic peninsula is an uplifted coastal plain ranging from 15 to 20 miles in width and trending from Grays Harbor northwesterly to the Cape Flattery axis. This plain ranges in elevation from 250 to 600 feet above sea level. Easterly it gradually rises and merges into the Olympic Mountains. To the south it becomes a part of the plain bordering Grays Harbor. Its surface is undulating in character and across it trend

Index Mountain Situated on Western Slope of Cascade Range. Skykomish River in Foreground.

several river valleys such as the Queniult, Queets, Hoh and Quillayute. The bed rock or pre-Pleistocene surface of this area consisting almost entirely of the Hoh formation has been unevenly veneered over with sands, clays and gravels of fluviatile origin, all of which are resting approximately horizontal.

Over a large part of this coastal plain the Pleistocene gravels and sands constitute the surface outcrops. It is only where the rivers have carved their channels through this covering and down into the underlying bedrock, that the strata of the Hoh formation are exposed. Sometimes these exposures consist of outcrops exposed only a few feet above the water's edge. In other cases they stand as high, bold bluffs and in a number of instances form rocky gorges through which the streams flow. Wherever the bed rock exposures outcrop away from the main stream courses they appear to represent prominent topographical features in the nature of monadnocks as related to the Pleistocene gravels.

Along the ocean shore line excellent exposures of the various strata composing the Hoh formation may be seen almost continuously. Occasionally, however, their upper surface passes down below sea level and the overlying Pleistocene sands and gravels form the ocean bluffs. The cliffs along the ocean, where composed of outcrops of the Hoh formation, range from a few feet to over three hundred feet above sea level and sometimes project out into the ocean as bold headlands so as to be impassable even at the lowest tides. The character of the outcrops are such that excellent exposures of the Hoh formation may be obtained at intervals over a large part of the western portion of the Olympic peninsula. Observations have been recorded in the field wherever possible. These observations have been tied into a continuous tape and compass traverse extended along the ocean shore line and up the more important streams. From these observations it has been possible to determine the lithologic character of the formation and to a certain extent the geologic structure which it now assumes.

LITHOLOGY.

The materials composing the Hoh formation are almost entirely of sedimentary origin although these in places have been subjected to slight metamorphism. If the assumption be correct that the quartzites and slates comprising the central portion of the Olympics also belong to the Hoh formation, the series as a whole may be regarded as having undergone differential metamorphism. The lithologic appearance of all the strata along the western border of the peninsula is typical throughout the entire area and generally can be easily distinguished from strata composing any of the formations in western Washington. They consist chiefly of sandstones, shaly sandstones, sandy shales, shales and conglomerates. The sandstones are commonly medium to coarse grained with a somewhat gritty appearance. They are nearly always firmly consolidated and possess a grayish brown color. Generally small angular fragments of black slate may be seen in them. These sandstone layers are often six or seven hundred feet thick and contain occasional lenticular layers of conglomerates. Often these massive sandstone belts, in a very short distance along their strike, rapidly grade over into conglomerates. Another characteristic phase of this formation is a bluish gray, coarse grained, gritty sandstone which when examined carefully is generally found to contain a considerable amount of muscovite, sometimes in sufficient amount to give the sandstone a somewhat banded and scaly appearance. It is generally in this type of sandstones that indications of petroleum are found. This sandstone sometimes becomes more or less shaly and is often interbedded with very narrow bands of dark brown shale. Upon weathering such outcrops are rapidly converted into mud banks so that the original geologic structure cannot be determined. Typical examples of this may be seen between the mouth of Hoh River and Hoh Head as well as at numerous other places northward along the shore line.

Certain sandstones in the Hoh formation have a laminated appearance so that they may be easily broken into huge slabs

each of which will average four or five inches in thickness. Good examples of this type are illustrated on Salmon River about two miles south of its junction with the Queets.

The shales range from a gray to a chocolate brown. They are sometimes massive but often occur in narrow bands alternating with more sandy material. Sometimes small lenticular masses of hard, flinty limestone are interspersed among the shales. These vary from three feet to fifteen feet in length and weather out in nodular form. As a rule the shales disintegrate much more easily than the sandstones and it is in this phase of the formation that the valleys and gullies have been largely carved. Along the beach the coves are almost invariably developed in the shaly phase of the formation and the higher headlands in the sandstone.

GEOLOGIC STRUCTURE.

During the course of field investigations observations were taken on the strike and dip at as many points as possible. These have been platted upon Map A, Plate IV. The structure has been definitely worked out along the coast but inland sufficient data are not at hand to determine the continuation of the coast structure. In the vicinity of Forks in Clallam County an anticlinal axis trends nearly south, crossing Bogachiel River in Section 33, Township 28 North, Range 13 West. (Plate XI.) This may continue southward as far as Hoh River and if so would cross it in Township 26 North, Range 12 West. More detailed data must be obtained in order to establish this point. A well defined syncline trending nearly north and south crosses Bogachiel River in Section 23, Township 28 North, Range 14 West. This has been traced as far as the Clallam-Jefferson County line, but has not been established farther to the south. Along the coast from Queets River northward to Point of Arches at least eighteen anticlinal and synclinal axes exist. With two or three exceptions these possess a northeast-southwest strike extending diagonally to the coast. In only a few instances have they been traced more than two miles inland. In many cases they have the appearance of minor warps developed on the limb

of a supposed large sub-marine anticlinal axis lying west of the present coast line. On the south side of Queets River an anticlinal axis crosses Salmon Creek about two miles south of its mouth and trends southwesterly into the Queniult Indian Reservation. A similar axis crosses Queets river about two miles from its mouth. Two miles north of Cape Elizabeth the bluffs composed of low-dipping Miocene sandstones are suddenly replaced by dark chocolate colored shales. While no actual contact between the two may be seen, yet the sharp discordance between the strike and dip give direct evidence of faulting. About one thousand feet north of this fault the shales are replaced by Miocene sandstones. Four miles east of Queniult River, in the southern portion of the big bend, a fault may be detected whose trend is North 45° West. The intervening area is heavily covered with fluviatile deposits so that the underlying bed-rock is entirely concealed. It is probable, however, that a narrow fault block of the Hoh formation has been thrust into the upper Miocene.

Along the coast between the mouth of the Hoh River and Hoh Head excellent exposures of the Hoh formation may be observed. (Plate XII). Hoh Head itself is composed largely of massive brown sandstone. At its western end a small cove has been developed and a synclinal axis trending nearly east and west has folded down a few hundred feet of overlying shale. Because of the non-resistance of the shales to erosion a cove has been formed at this point. Immediately south of Hoh Head and north of the high conglomerate point just north of the mouth of Hoh River a synclinal axis trends North 30° East. Where this axis intersects the coastline a cove has been developed in an extensive series of sandy shales underlying the massive sandstone of Hoh Head. From Hoh Head northward along the coast for a distance of ten miles an anticlinal axis appears to lie just off the shore beneath the waters of the ocean. It passes inland again in Section 1, Township 27 North, Range 15 West and crosses Quillayute River about one-half mile east of Mora. Northward from the mouth of the Quillayute the Hoh forma-

tion is involved in several synclines and anticlines and finally passes beneath the Eocene(?) basaltic formation exposed at Point of Arches. The formation is exposed in places along Dickey River east of Ozette Lake but insufficient data have been obtained to determine its structure. The eastward continuation of this formation has been traced into Township 29 North, Range 12 West, where it is found to be badly broken and shows the effect of greater metamorphism. Whether it extends eastward into the heart of the Olympic Mountains from present evidence cannot be determined.

STRATIGRAPHY.

Wherever possible along the coast, detailed stratigraphic measurements of the strata in the Hoh formation were made. In every case such sections have been tied into traverse surveys. A continuous traverse was run from Moclips to Cape Flattery and the station numbers referred to in the following sections are points upon that traverse. There are insufficient data at present to determine in which particular portion of the Hoh formation each of these sections belongs. Inland from the ocean shore line the exposures are so limited that it is impossible to correlate one with another. Faulting has also complicated the structure.

The following section represents partial measurements from Station No. 133 at a point north of the mouth of Kalaloch River to a point at the mouth of Cedar River:

Top of Section	*Feet*
Massive brown sandstone	110
Massive sandstone	180
Covered	120
Banded sandstone with intercalated shale bands	36
Interbedded shale and sandstone, sandstone predominating	22
Covered	400
Massive sandstone	200
Covered—but where exposed mostly shale	500
Massive sandstone	60
Massive sandstone	53
Banded sandstone	6
Massive sandstone	28
Banded sandstone	2
Massive sandstone	6
Banded sandstone	5
Massive sandstone	7

Top of Section	*Feet*
Shale	1
Massive sandstone	7
Covered—probably shale	150
Shale	150
Massive sandstone	100
Banded sandstone	2
Massive sandstone	6
Banded sandstone	9
Massive sandstone	25
Banded sandstone	6
Alternating bands of shale and sandstone	24
Shale	36
Chocolate colored shale	50
Massive sandstone	20
Shale—At station No. 170	20
Mostly covered—where exposed a massive gray sandstone	400
Covered—where exposed hard conglomerate and metamorphic rock—largely determined from stacks located at intervals along the coast. This region may represent the true base of the Hoh formation.	
Base of Section	
Total	2741

The following section was measured along the coast from Station No. 360 to No. 407. The base of this section is at Station No. 360. The line along which the section was measured is approximately five miles north of the mouth of Quillayute River, in southwestern Clallam County.

Top of Section	*Feet*
Brown massive sandstone	100
Massive brownish gray sandstone with some conglomerate	1500
Gray sandstone	200
Interbedded gray sandstone and shale	300
Sandy shale	600
Base of section	
Total	2700

CONDITIONS OF DEPOSITION.

The Hoh formation was laid down either on the coastal margin of the ocean direct or in an extensive embayment of the ocean. The fact that massive conglomerates and coarse-grained gritty sandstones alternate with enormous thicknesses of shale suggest oscillations in the depth of the sea-floor. Occasionally fragments of carbonized wood or small lenticular seams of lignite occur interbedded with gravel or conglomerates. These conglomerates may represent deposits formed along former beaches or even along the lower portions of stream

valleys. A microscopic examination of the shale phases of the formation indicate the presence of marine diatoms and foraminifera. These forms of life may have thrived in the deeper waters. Because of the total absence of marine invertebrate fossils other than those just mentioned and the absence of plant remains, it is impossible to arrive at any conclusion concerning climatic conditions.

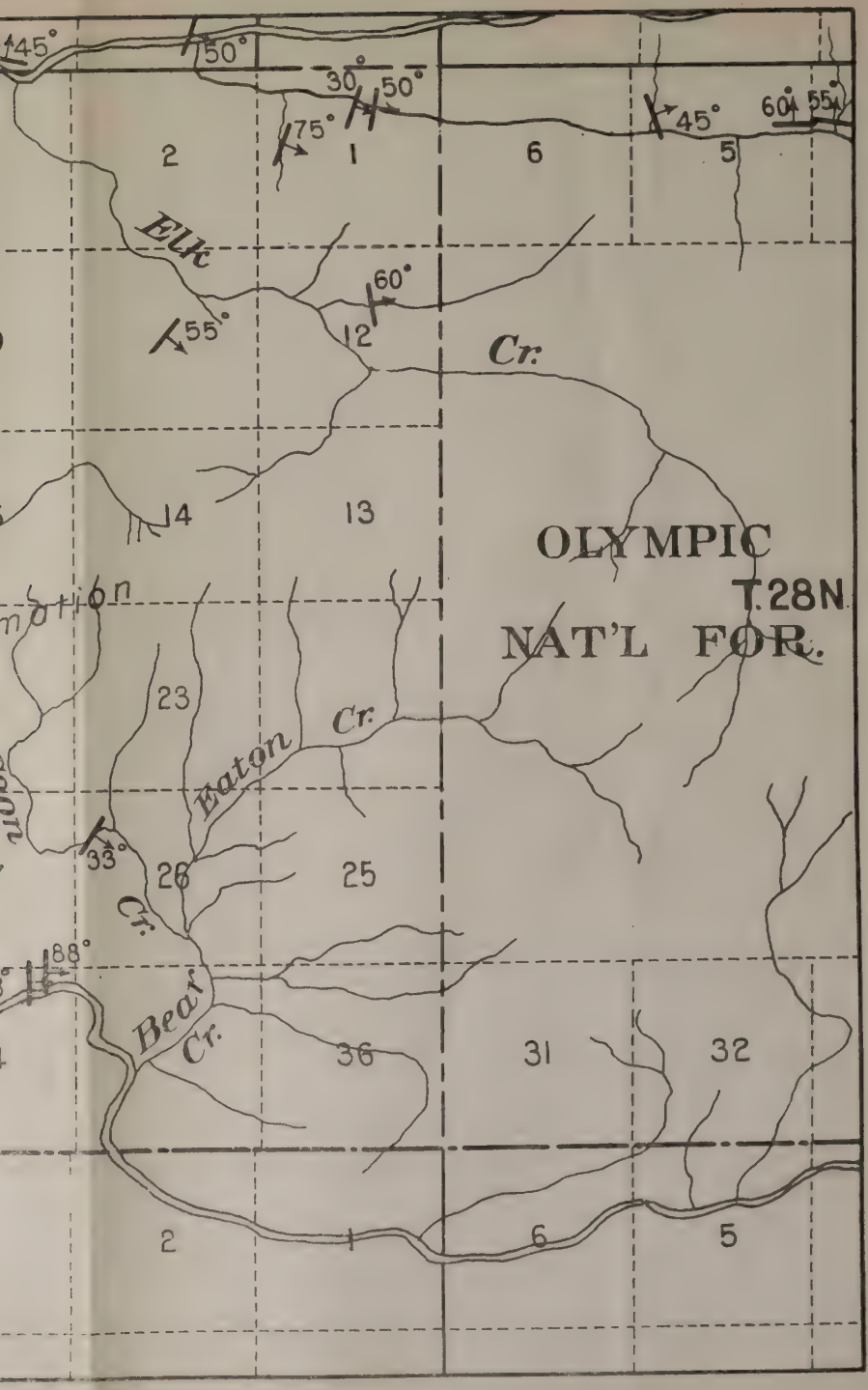
FOSSILS.

Although a careful search has been made for fossil Molluscan remains within the Hoh formation, not a single fragment has as yet been found. A portion of a small leaf of undetermined species was collected from the first headland south of Raft River. In the vicinity of Hoh Head brownish colored shales outcrop which upon microscopic examination are found to contain numerous remains of diatoms. Nearly all the shale exposures which show the presence of diatom remains possess the odor of petroleum. Fragments of shale brought up from a depth of seventeen hundred feet in the oil well at Forks contain the remains of numerous foraminifera. These shales also have a pronounced odor of petroleum.

CORRELATION.

The exact age of the Hoh formation is not certain. It is certainly older than the Miocene and apparently older than the Eocene (?) basalts as exposed south of Cape Flattery. It is less metamorphosed than the older Carboniferous and Triassic rocks of the San Juan Islands and northern Cascades. It might possibly be of the same age as those just mentioned but have undergone a lesser degree of metamorphism. As far as known no massive intrusive rocks occur within the Olympics. If they are present they are of minor importance. This fact might account for the difference in degree of metamorphism and still allow them to be of Carboniferous or Triassic age. They do not, however, contain the large limestone masses that are so commonly associated with those older formations in the northern Cascades, San Juan and Vancouver islands. They do not bear any resemblance to the upper Cretaceous rocks as ex-

Quillayute
RIVER
CALAWAH
SOLEDUCK
BOGACHIEL
SYNCLINAL AXIS
Montesano Formation
Maxwell
112
113
114
115
111
50°
45
60°
35
10°
15°
75°
68°
R14W.


45°
50°
30°
50°
75°
45°
60°
55°
2
1
6
5
ELK
60°
55°
12
Cr.
14
13
OLYMPIC
T.28N
NAT'L FOR.
23
Baton
Cr.
33°
26
25
Cr.
88°
Bear
Cr.
36
31
32
2
1
6
5

posed along the northeast coast of Vancouver Island. They are presumably older. It is quite possible that they may be of Jurassic age. These suggestions are based entirely upon lithological evidence which forms a very insecure basis for correlation.

CHICO FORMATION.

GENERAL STATEMENT.

The Cretaceous deposits of the Pacific Coast have been divided into three divisions. These are referred to as the Knoxville or lower Cretaceous, the Horsetown or middle Cretaceous, and the Chico or upper Cretaceous. With the exception of the possible occurrence of the Knoxville in Whatcom County, the Chico formation is the only Cretaceous deposit known within the western half of the state.

Chico strata are known to occur in the Queen Charlotte group, as well as on the northeast side of Vancouver Island.*

GEOGRAPHIC DISTRIBUTION.

In western Washington strata of Cretaceous age are found in the northern portion of the San Juan Islands and in the northern portion of Whatcom County. With the exception of these localities, rocks of Cretaceous age are unknown in western Washington. However, they may possibly exist deeply buried beneath an enormous overburden of Tertiary strata. The upper Cretaceous or Chico strata as exposed in the San Juan Islands are the southeastern extension of a thick series of sedimentary rocks exposed along the northeast coast of Vancouver Island. They disappear to the east in Sucia Island, but may possibly exist beneath the glacial covered plains north of Bellingham.

In the San Juan group, the Chico formation composes all of Sucia Island, Patos Island, the extreme northern part of Orcas Island, all of Waldron Island, Stuart Island and several smaller unnamed islands off the north end of San Juan Island

* Descriptions of new Cretaceous fossils from Vancouver and Sucia islands. Proceedings, Academy of Natural Science, Philadelphia, vol. 13, pp. 313-314. 1861.

proper. To the northwest these outcrops continue to Saturna, Mayne, Pender, and Galiano islands on the British side.

CHARACTER OF OUTCROPS.

The general character of the outcrops has been largely determined from the structure which the strata assume. The harder conglomerates and sandstones constitute the higher hills and mountains while the valleys and sub-marine channels have for the most part been developed in the softer shale members. On Orcas Island the softer Cretaceous rocks form low hills compared with the harder metamorphosed formations just south as represented in Turtle Back Mountain and Mt. Constitution. Sucia Island is nearly divided by an east-west embayment which has been carved into the soft shales leaving the harder rock to form the north and south portions of the island. Waldron Island is more nearly circular and owes its general form to the resistent character of the conglomerates and sandstones which so largely compose it.

LITHOLOGY.

The Chico formation as exposed in the San Juan Island group is composed of massive and bedded shales, and extensive belts of alternating beds of shales and sandstones. The series, as a whole, has not been metamorphosed. The pebbles composing the conglomerates have nearly all been derived from the underlying metamorphic formations. They are composed of quartzites, granite, diorite and gabbro gneisses. The pebbles range in size from that of a marble to boulders over five feet in diameter. Probably from 4 to 6 inches in diameter is the average size. These conglomerate masses resist weathering and constitute the more important topographic features of the formation. Interbedded with these conglomerates are irregular shaped bands of grit and sandstone. Commonly these widen out so as to allow the conglomerate belt to develop into an alternating series of sandstones and conglomerates. Sometimes they grade over into massive sandstones which contain small cross-bedded lenses of conglomerate and then back again into conglomerate proper.

The sandstones are most commonly coarse-grained, of a light brownish gray color and sometimes showing cross-bedding. The shales vary from a light gray to a predominating chocolate brown. They are often distinctly bedded, although sometimes massive. On the north side of Orcas Island they alternate as very narrow bands with sandstone.

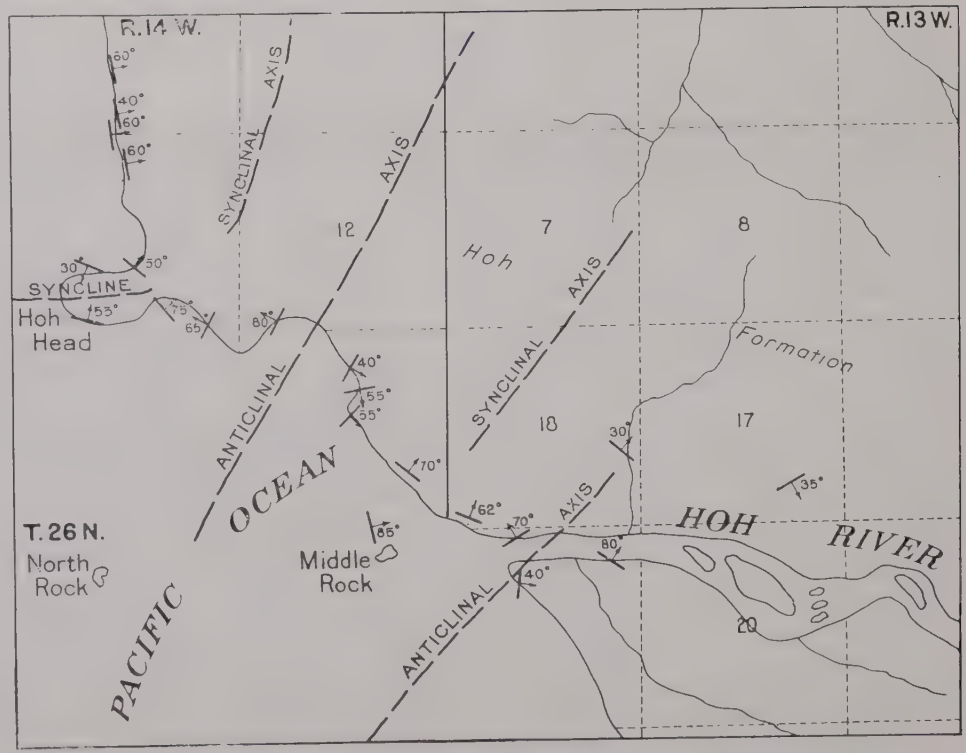
No igneous rocks, either extrusive or intrusive, have been found associated with the Chico formation in the San Juan Island group.

CONDITIONS OF DEPOSITION.

The Chico formation as represented in the northern part of the San Juan Islands in common with that of the east coast of Vancouver Island was deposited in an embayment of the ocean formed between the main axis of Vancouver Island and the British Columbia mainland. This arm appears to have been cut off at the south of the Straits of Rosario by a mountainous mass extending from the present site of the Cascades, through the San Juan Island group into Vancouver Island. The lower portion of the formation appears to have been formed under comparatively shallow water conditions, the middle portion of the formation in deeper water, and the upper portion under shallow water and in part under fluviatile conditions. The latter is evidenced by the extensive series of non-fossiliferous interbedded conglomerates and sandstones.

GEOLOGIC STRUCTURE.

The strata involved in the Chico formation in the northern portion of the San Juan group in common with those along the northeast coast of Vancouver Island have been folded into a series of northwest to southeast anticlines and synclines. On the north side of Orcas Island the strata rest unconformably upon the older metamorphic formations and dip at an average angle of 60° to the northeast. On Waldron Island the formation has been folded back so as to form the nose of a syncline.



Geologic and Structural Map of the Region from Hoh Head Southward to the Mouth of Hoh River.

CHAPTER III.

EOCENE FORMATIONS.

GENERAL STATEMENT REGARDING THE TERTIARY AS A WHOLE.

West of the crest line of the Cascade Mountains within the state there are extensive deposits of Tertiary age. These deposits consist of rocks of sedimentary and igneous origin. The sedimentary materials are composed of sandstones, shaly sandstones, shales and conglomerates. The igneous rocks consist of lava flows of varying texture, volcanic tuffs, dikes, sills and intrusive plutonic rocks. The formations of surface origin possess a maximum aggregate thickness of over 35,000 feet not all of which is present in any one particular locality. For the most part they are firmly indurated but have not been metamorphosed. The basement complex upon which they rest is composed of quartzites, slates, schists, gneisses and various types of intrusive rocks all of which have been subjected to more or less deformation and erosion. Formations of Tertiary age are largely absent from the central portion of the Olympic Peninsula, the San Juan Islands and portions of the Cascade Mountains.

The following subdivisions of the Tertiary have been made within the western portion of the state upon a basis of the information obtained in this investigation:

QUATERNARY	Diastrophism, volcanism, glaciation and erosion. Development of the present Cascade Range.
PLIOCENE	Largely a record of diastrophism and erosion. Igneous activity in eastern Washington. The upper portion of the Montesano formation may in part belong here.
MIOCENE	Upper Miocene. Montesano formation containing Yoldia strigata Zone. Unconformity— Lower Miocene. Wahkiakum Horizon containing Arca montereyana Zone.
OLIGOCENE	BLAKELEY HORIZON. Characterized by Acila gettysburgensis Zone. PORTER HORIZON. Characterized by Turritella porterensis Zone. LINCOLN HORIZON. Characterized by Molopophorous lincolnensis Zone.
EOCENE	Upper Eocene Tejon formation. Igneous, estuarine marine and lacustrine phases. Lower Eocene Martinez formation. Wanting.
	Basement complex of Palaeozoic and Mesozoic rocks largely metamorphosed.

Deposits containing a fauna representative of the Martinez epoch or lower Eocene have not as yet been recognized within the state. It is possible, although not certain, that the Swauk formation of eastern Washington may in part be the equivalent of the Martinez. Deposits of marine, estuarine and fresh water origin together with intercalated flows of lava and tuff are well developed and possess a maximum thickness of 15,000 feet. The marine sedimentary phases of these deposits contain a rich marine invertebrate fauna characteristic of the Tejon epoch or upper Eocene of the Pacific Coast. The lacustrine or fresh water phase of the formation is best developed in the central and eastern portion of the Cascade Mountains. The estuarine phase occurs in the western foothills of the Cascades and in the form of small lenses interbedded with the predominating marine phase of southwestern Washington. The volcanic phase, which consists of lavas ranging in composition from basic andesites to acidic basalts, occurs in the form of flows of varying thicknesses intercalated with the marine and estuarine sediments. These lavas range in texture from typical volcanic ash and flow breccias to microcrystalline and glassy types. The materials have in part at least escaped to the surface through fissures and accumulated both on the land surfaces as well as upon the floor of the upper Eocene embayments. Faunal and floral evidences indicate the existence of a tropical to sub-tropical climate during the entire Tejon epoch.

During the Oligocene epoch marine embayments were much more widely extended throughout Washington west of the present site of the Cascades than during the Eocene. The deposits formed in these embayments attained a maximum aggregate thickness of 14,000 feet. They are almost entirely of marine origin and contain abundant and in many cases excellently preserved invertebrate faunas. Three distinct faunal zones can be recognized. The strata identified by each of these zones are referred to as horizons. The oldest Oligocene within the western portion of the state is identified as the Lincoln Horizon and contains the Molopophorous lincolnensis Zone. The middle di-

vision is known as the Porter Horizon or Turritella porterensis Zone and the upper division as the Blakeley Horizon or Acila gettysburgensis Zone. The materials deposited in the Oligocene embayments consist largely of shaly sandstones and sandy shales together with minor amounts of conglomerate, sandstones and shale. Volcanic lava flows are almost entirely absent from the Oligocene formations with the exception of certain areas north of Columbia River in Pacific County. Many of the shales and sandstones are derived from rock of volcanic origin. The principal areas where deposits of Oligocene age now form surface outcrops are along the north border of the Olympic Peninsula, the Puget Sound Basin and southwestern Washington.

During the lower Miocene the marine embayments became much more restricted than during the Oligocene and the deposits formed are now found outcropping in the vicinity of Clallam Bay on the south shore of the Strait of Juan de Fuca, in the Grays Harbor region and on the north side of Columbia River in Wahkiakum County. The maximum thickness in the region of Clallam Bay as well as at Grays Harbor is approximately 4,000 feet. The materials are predominatingly coarse-grained sandstones, shales and conglomerates. They contain a fairly abundant fauna which is quite distinct from the older Oligocene faunas as well as the younger upper Miocene faunas. One of the most common and characteristic species occurring in this fauna is *Arca montereyana* Osmont. The fauna occurring within these deposits is referred to as the Arca montereyana Zone and the strata containing the fauna as the Wahkiakum Horizon. Future studies may determine that this horizon is the equivalent of the Monterey formation of California. Sufficient evidence is not now available to warrant such a direct correlation.

At the close of the lower Miocene the Pacific Coast was subjected to intense deformational movements. A large part of the former sea floor was elevated above sea level. Sediments

formerly deposited were folded and faulted. The newly elevated land areas were attacked by erosional agencies and the newly derived sediments were during the course of upper Miocene time deposited in newly developed embayments. In Washington nearly all of the western portion of the state was elevated during the middle Miocene. During the upper Miocene two small embayments were formed. One of these embayments was situated on the western side of the Olympic Peninsula near the mouth of Quillayute River and the other to the north and east of Grays Harbor. Apparently the land area during the upper Miocene extended much farther to the west than at present. The upper Miocene sediments in western Washington consist of sandstones, conglomerates, and shales of marine, shallow water origin and possess a thickness of 2,000 feet. Marine invertebrate faunas are abundant and are closely related to the Empire fauna of Oregon and the San Pablo of California. Sufficient evidence is not as yet available to warrant making correlation of the upper Miocene of Washington with the Empire or San Pablo formations. The upper Miocene fauna of Washington is referred to as the Yoldia strigata Zone from the presence of this most characteristic species. The strata containing this fauna are termed the Montesano Horizon. Montesano formation might appropriately be used.

Along the western slopes of the Cascade Mountains there are extensive deposits of andesitic lavas and interbedded tuffs and clays. The older Eocene deposits pass beneath these lavas along the western margin of the foothills of the Cascades. Exposures are well defined from Enumclaw to Cedar Lake in King County and the name Enumclaw volcanic series is provisionally applied to them. They are at least two thousand feet in thickness in the region studied. They may be the western extension of the Keechelus Volcanic Series which have been mapped in the Snoqualmie Folio by George Otis Smith and F. C. Calkins.*

* Smith, G. O., and Calkins, F. C. Snoqualmie Quadrangle, U. S. Geol. Surv. Folio 139, 1906.

In eastern King County, north of Cedar Lake, there are exposures of granodiorites which are intrusive into a series of old metamorphic quartzites, slates and schists. These intrusive rocks may be traced easterly to the summit of the Cascade Mountains where they have been mapped in the Snoqualmie quadrangle as the Snoqualmie Granodiorite and are regarded as being of Pliocene age. In the vicinity of Cedar Lake they are also covered with the Enumclaw andesites.

No marine deposits of Pliocene age have as yet been recognized within the state of Washington. It is possible that they may exist and be buried beneath a mantle of glacial drift. It is more probable that they were never formed and that the western part of the state as well as the eastern was a land area. The geological record of the Pliocene in western Washington with the exception of the Cascade Mountains must be sought in terms of diastrophism and erosion.

Early in the Quaternary or possibly in late Pliocene time the western coast of North America was again subjected to deformational movements which caused for a second time the uplift of the Sierra Nevadas and Cascades. The present Cascade Mountains of Washington were developed by a series of differential uplifts. The original peneplained surface of the present site of the Cascades was warped during the uplift and the broad features of the drainage adjusted themselves to the structure. Volcanic energies became concentrated at certain points beneath the surface of the uplifted peneplain and upon it as a base prominent volcanic cones were developed.

GENERAL STATEMENT OF THE EOCENE.

No record is available of the geologic history of western Washington during the early Eocene epoch. The region was presumably a land area not much elevated above sea level. The geological history of Washington during the upper Eocene can be partially interpreted from a fairly complete record as exhibited in the surface rock exposures. Marine, estuarine and brackish water faunas are abundant as well as land floras. An examination of the marine invertebrate species occurring within

these faunas indicates a very close relationship to the upper Eocene of California, in fact so close as to warrant a direct correlation with the Tejon. The basement upon which the upper Eocene sediments were deposited is in most localities concealed. In Skagit, Whatcom and Snohomish counties estuarine deposits are resting directly upon schists and slates of Palaeozoic or Mesozoic age. In the central and eastern portions of the Cascade Mountains lacustrine deposits of Eocene age are resting upon extensively eroded peridotites and granodiorites as well as slates and quartzites of Mesozoic age. In the southwestern portion of the state as well as in the Puget Sound Basin the basal contact relations cannot be determined as they are nowhere exposed at the surface. During the upper Eocene the Cascades as a range did not exist. The central and southern portions of the range within the state were presumably not greatly elevated above sea level while the northern portion may have possessed some relief. The regions now involved within the San Juan Islands as well as the central portion of the Olympic Mountains were apparently land areas which had been uplifted at the close of the Jurassic. Differential oscillations of the land areas as well as the sea floor were taking place during the upper Eocene or Tejon epoch. Coincident with these movements the embayments of the ocean were shifting both in area and depth. There was a consequent change in the environmental conditions under which the marine invertebrate fauna was existing. A record of these conditions is in part preserved in the character and distribution of the fossil faunas as well as the lithologic character of the sediments in which the faunas were buried. On the present site of the Cascade Mountains fresh water lakes of considerable size were in existence. These basins were continuously changing in size and may at times have had direct or indirect connections with the estuaries to the west in central King, Pierce and Lewis counties.

GEOGRAPHICAL DISTRIBUTION.

Surface outcrops of upper Eocene age occur in the western foothills of the Cascades, in the Puget Sound Basin, on the

north flanks of the Olympic Mountains, on the southeastern portion of Vancouver Island, in the lower Cowlitz Valley and in the hills of southwestern Washington. Over considerable portions of these areas they are more or less obscured by later lavas or tuffs or by deposits of glacial drift. As a result the surface exposures of the Eocene formations appear in the form of isolated outcrops. In some cases it is possible to determine definitely that the intervening covered areas are underlain with strata of Eocene age. In other instances their presence is only conjectural. On the maps accompanying this report an effort has been made to represent the distribution of the preglacial formations. Those areas where the surface exposures are of Pleistocene age but where there is some evidence to indicate that the underlying bedrock formations are Eocene have been mapped as Eocene. Where the contacts between Eocene and other bedrock formations are covered the probable approximate position of the contact lines have been inserted upon the maps. These facts should be borne in mind whenever detailed use is made of the maps.

The surface distribution of the marine, estuarine and basaltic phases of the Eocene are also designated upon the maps. Usually they are interbedded with one another but one phase predominates over the other. In every case the predominating phase has been mapped.

Along the north side of the Olympic Peninsula, Eocene basalts together with interbedded tuffs and shales trend from Port Discovery Bay westerly to the Point of the Arches south of Cape Flattery. Between Port Angeles and Port Crescent a tongue like mass extends northerly to the Strait of Juan de Fuca. This belt of lava rests upon the older Mesozoic sedimentaries of the Olympic mountains and in turn forms the basement for the overlying marine Oligocene deposits.

The basalts just described extend southerly around the east and south flanks of the Olympic mountains and are also exposed in the Bald Hills of central Kitsap County in the Puget Sound Basin. If all the overlying deposits of glacial drift were re-

moved exposures of basalt would presumably occupy the entire southern portion of the Puget Sound Basin from the Olympic mountains to the western margin of the Cascades. Outcrops of basaltic lava and interbedded sandstones and shales occur in the hills south and southeast of Seattle in King and Pierce counties. Similar deposits are present in Thurston, Lewis and Cowlitz counties. In Pacific, Wahkiakum and Grays Harbor counties extensive exposures occur intimately associated with younger marine deposits of Oligocene, lower Miocene and upper Miocene age.

In the foothills of the Cascades in western Skagit and Whatcom counties there are small local deposits of sandstones and shales of probable lacustrine origin formed contemporaneously with the estuarine and marine deposits farther south.

The southeastern portion of Vancouver Island from Albert Head westerly to Sambrio River is composed of Eocene basalts and basaltic tuffs. Interbedded with the tuffs are shales containing typical marine fossil invertebrates.

LITHOLOGY.

The Eocene sedimentary rocks consist of medium to coarse grained sandstones, thinly bedded and massive shales, alternating thinly bedded shales and sandstones, sandy shales, shaly sandstones, carbonaceous shales and coal seams. The coarse grained sandstones are often arkosic in composition and show no well defined bedding planes. Occasionally they exhibit cross bedding and contain fragments of carbonized wood. When examined microscopically they are found to be composed of small rounded grains of quartz together with angular and rounded grains of badly altered feldspar and fragments of biotite and hornblende. The cementing material consists of silica and iron oxide. The sandstones when fresh possess a gray color but where exposed to weathering range from brownish gray to brownish yellow.

The shales range from a fine grained fissile condition to a thinly bedded and laminated condition. Other varieties are mas-

sive and show no indications of stratification. They break with a distinct conchoidal fracture. Still other varieties are carbonaceous and grade from that condition to an impure shaly lignite. Very commonly the shales are sandy and pass to a condition where they would be classed as a shaly sandstone. The shales range in color from a light gray to a dark chocolate. Certain of the shales upon microscopic examination are found to be composed of fine volcanic products. Some of the coarser sandstones are composed of reworked volcanic tuffs.

Commonly the lavas are composed of flow breccias intermixed with coarse pumice and ash. These have been subjected to the action of running water at the time of deposition. Extending upward from the contact, the sorting action of water becomes more pronounced. Illustrations of this phase of deposit may be seen in the small rock outliers south of Seattle at Duwamish Station. They were probably formed during an epoch of volcanic activity in close proximity to a region where streams were emptying into a marine embayment as marine fossils are often associated with deposits only a short distance away.

The thickness of these several phases varies from place to place. Sandstone belts exist having a thickness of nearly 1,000 feet. There are numerous belts ranging in thickness from 25 to 300 feet. These belts vary in thickness as well as lithologic composition when traced along their strike. Extensive belts composed of alternating layers of shale and sandstone of varying thickness are very characteristic and make up a considerable portion of the upper Eocene deposits.

Andesitic lavas and tuffs in certain areas constitute a large part of the Eocene of western Washington. Exposures may be seen along Columbia River, Cowlitz River, in the Puget Sound Basin and along the north flanks of the Olympic Mountains. In nearly all instances they are interbedded with the marine or estuarine sediments. In many places they might be mistaken for flows of Pliocene or Pleistocene age but areal mapping tends to show that marine Eocene strata lie either above them or interbedded with them. The shales below them are commonly baked

near the contact. Occasionally the sedimentary rocks above and below certain flows show the action of heat. Such belts of andesite were presumably intruded in the form of sills contemporaneously with the andesitic extrusions. Instances of this condition may be seen in the rock hill outliers at Duwamish Station south of Seattle as well as in the rock exposures in Cowlitz County.

The volcanic materials range in mineralogical composition from basic andesites to acidic basalts. They grade in texture from dense glassy lavas to coarse grained granular types and from fine grained volcanic ash to coarse ejectamenta. These several types are often intricately mixed. In certain localities as along Columbia River individual flows may be seen resting upon one another. Between the different flows there are occasionally deposits of light colored or yellow clay ranging from a few inches to a foot or more in thickness. Carbonaceous material is often included within the clay indicating the probable existence of vegetation during the intervals between the outpouring of lava. Commonly deposits of light colored volcanic tuff of considerable thickness are intercalated with the lava flows.

It very often happens that thick layers of tuff breccia have thin tongues of glassy lava intercalated. During the accumulation of the series quantities of ash and boulders were in contact with liquid lava and were in part mixed and carried along with it. In certain areas these deposits were forming on tidal flats or estuarine basins and much of the finer material was sorted and partially stratified. Marine fossils are occasionally found within these partially baked shales and tuffs.

Within the lower Cowlitz Valley and in King and Pierce counties narrow andesitic dikes and sills are of common occurrence. They range in thickness from a few inches to over fifty feet. In several places as at Coal Creek in Cowlitz County they are clearly feeders for the interbedded andesite flows.

Thin sections of all these various phases were examined microscopically. Partial chemical analyses as well as mineral analyses place them in the rock classification at the boundary

between andesites and basalts. A number of specimens were without question typical basic andesites, while other samples proved to be basalts.

THICKNESS.

Presumably large amounts of the total sediments deposited during the upper Eocene have been removed by erosion. The Eocene strata have been folded and in part covered so that at no locality can the entire thickness be observed. In King County detailed stratigraphic surveys have been made along Green River. The base of the formation was not found at any point. From a series of careful measurements made in the canyon of Green River the Eocene deposits exposed were estimated to have an approximate thickness of 8,000 feet. In the vicinity of New Castle and Issaquah the Eocene sedimentary rocks have a thickness of 2,000 feet and rest upon andesites which are also of probable Eocene age. They are overlain by marine Oligocene sediments.

In Pierce County in the region of Carbon River and southward the Eocene strata attain a thickness of 14,000 feet. Here the base of the formation is also unknown. In Thurston County Eocene rock outcrops occur as isolated exposures. In the region between Tenino and Centralia interbedded sediments and lavas are dipping to the south at low angles and possess an estimated thickness of at least 2,000 feet.

In northern Cowlitz and southern Lewis counties sedimentary and igneous rocks of Eocene age occur at intervals from the town of Winlock in the north to Castle Rock in the south. The lowermost beds are exposed near the town of Castle Rock. Successively higher strata are encountered to the north and the uppermost beds are exposed near Winlock. Approximately 8,000 feet of strata are involved in this section.

In northern Clallam County in the vicinity of Port Crescent Eocene lavas and shales possess a total thickness of about 4,000 feet. In the central and eastern Cascade Mountains the Swauk, Teanaway and Roslyn formations, all of Eocene age, have a total maximum thickness of 12,000 feet.

STRATIGRAPHY.

The details of the stratigraphy are given in the descriptions of each area. The most complete sections have been measured in portions of King, Pierce and Lewis counties. In the other areas the exposures are so scattered that only fragmentary sections can be made. The type marine section for western Washington is the one just described as occurring between Winlock and Castle Rock. The following lithologic subdivisions are recorded:

	Feet
Top of Section	
Massive clay shale, grading in places into sandy shale, as exposed along the banks of Olequa Creek south of Winlock and also in the banks of Cowlitz River in Section 5, Township 11 North, Range 2 West, at locality 239. These strata constitute the basal member of the Oligocene	600
Chiefly sandy shale grading into massive clay shale of a dark brownish gray color. Exposures of this member are not very abundant but contain occasional specimens of *Venericardia planicosta* and *Turritella uvasana*. This is the uppermost marine Eocene as yet recognized within the state	960
Shaly sandstone	100
Slightly banded sandy shale	130
Slightly carbonaceous sandy shale	50
Sandy shale	430
Laminated sandstone and sandy shale	150
Shale slightly sandy. The upper portion of this member contains an abundant marine Tejon fauna	340
Massive clay shale. The equivalent of the shales occurring in the bank of Cowlitz River in Section 25, Township 11 North, Range 2 West	50
Sandy clay shale. Base of upper marine division	70
Yellowish brown sandstone with interbedded lignitic layers. These sandstones often grade into carbonaceous sandy layers. The fauna occurring within these strata are entirely of brackish water origin	520
Fresh water beds. Light gray massive clay shales, containing numerous fresh water Eocene invertebrate fossils. Fossil localities 295 and 303 occur in these beds.	130
Brackish water beds. Sandy shales and shaly sandstones grading into brownish yellow coarse grained sandstone all of which is more or less carbonaceous. Faunas at localities 231, 234 and 300 occur in these beds	550
Marine beds. Sandy clay shales grading into shaly sandstones. Faunas at localities 240, 240b, 299, 241, 238, 236, 298, 294 and 294a occur in these strata. The basal portion of this belt grades into beds of brackish water origin. Below this zone no detailed measurements have been made. The underlying strata are those involved in the area between Castle Rock and Olequa. Just below, andesite and tuffs are intercalated with the sedimentaries	390
Total thickness of measured Eocene strata	4470
Possible thickness of unmeasured strata involved in area between Castle Rock and Olequa	6000
Possible total thickness of Eocene as exposed in the lower Cowlitz Valley	10,470

The above section is involved in a continuous northeasterly pitching monocline. The lower portion of the section consists

of alternating belts of lava, tuff, shale and sandstone. The upper portion is entirely composed of sediments, having a thickness of nearly 4,000 feet as indicated above. The lower beds of the upper measured portion are of marine origin. Above these in sequence are brackish water strata, fresh water, brackish water and finally marine at the top. Resting upon the uppermost Eocene beds are sandy shales containing a fauna of lower Oligocene age. The contact relations suggest an unconformity.

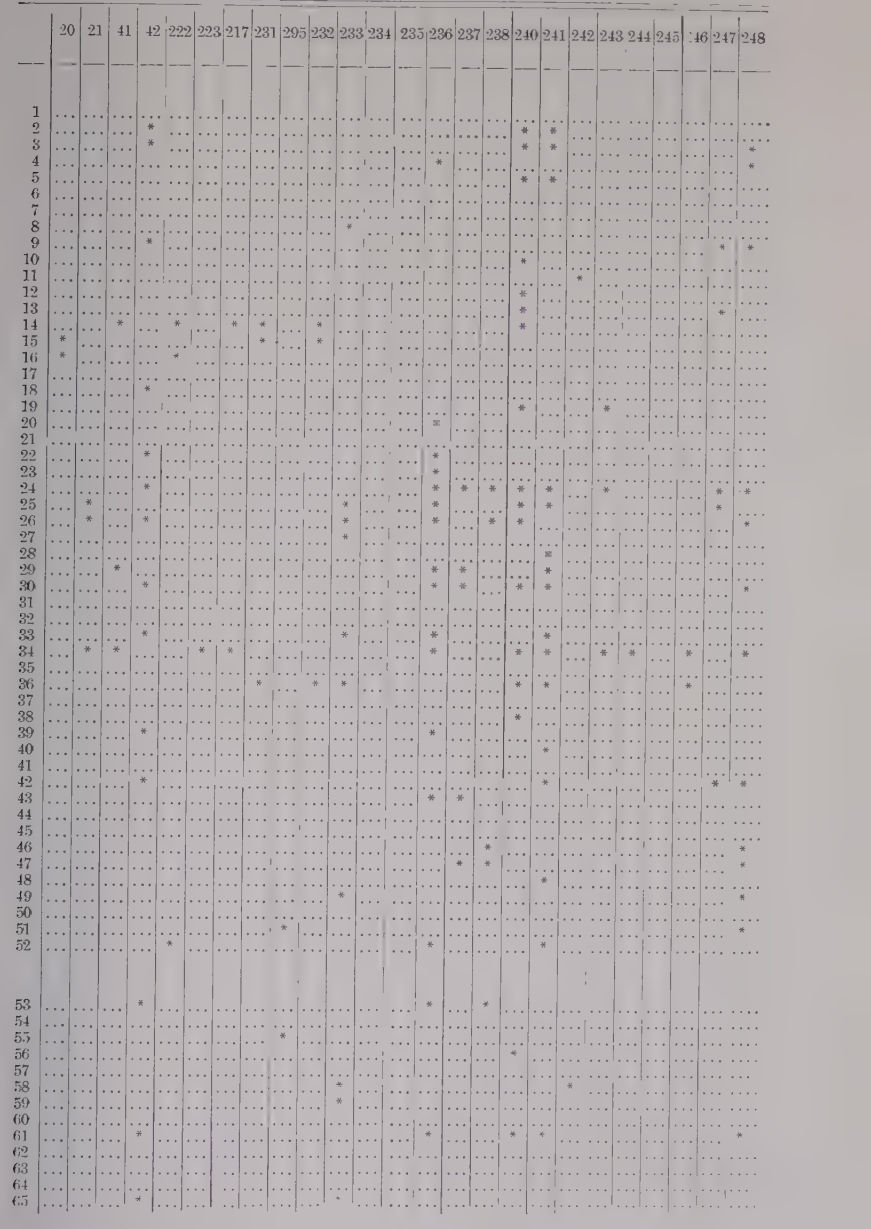
FAUNA.

A total of 130 species of invertebrate fossils are known to occur within the upper Eocene strata of western Washington. Of these 52 are Pelecypods and 77 are Gasteropods. In addition there are two species belonging to the Scaphapoda and two species to the Cephalopoda. The following table includes a list of the upper Eocene fauna of the state as known up to the present time as well as the localities at which the different species occur.

EOCENE.

LIST OF SPECIES	1	2	3	4	5	6	7	8	11	17	17	18
PELECYPODA												
1 Avicula pellucida Gabb	*											
2 Barbatia morsei Gabb					*							
3 Cardium breweri Gabb	*				*	*	*				*	
4 Cardium cooperi Gabb	*				*							
5 Cardium olequahensis Weaver												
6 Corbula hornii Gabb	*											
7 Corbula n. sp.	*											
8 Crassatellites washingtonensis Weaver					*							
9 Crassatellites grandis Gabb	*				*							
10 Crassatellites merriami Weaver												
11 Crassatellites dalli Weaver												
12 Crassatellites cowlitzensis Weaver												
13 Crassatellites compacta Gabb	*				*							
14 Cyrena brevidens White		*	*						*			*
15 Corbicula cowlitzensis Weaver								*				
16 Corbicula eufaulaensis Weaver								*				
17 Diplodonta polita (Gabb)	*											
18 Glycimeris sagittata (Gabb)							*					
19 Glycimeris eocenica (Weaver)												
20 Glycimeris eocenica var landesi (Weaver)												
21 Leda vaderensis Dickerson	*											
22 Leda gabbi Conrad	*		*				*					
23 Leda sp.	*											
24 Meretrix hornii Gabb	*				*		*					
25 Meretrix uvasana Conrad	*					*						
26 Meretrix ovalis Gabb					*		*					
27 Meretrix olequahensis Weaver												
28 Meretrix longa? Gabb												
29 Marcia quadrata (Gabb)	*				*		*					
30 Marcia conradana (Gabb)	*				*	*	*					
31 Macrocallista andersoni Dickerson	*											
32 Macrocallista vaderensis Dickerson	*											
33 Modiolus ornatus Gabb	*				*	*	*					
34 Ostrea idriaensis Gabb	*		*		*		*			*	*	
35 Ostrea olequahensis Weaver	*										*	
36 Ostrea fettkei Weaver	*		*									
37 Pecten cowlitzensis Weaver												
38 Pecten landesi Arnold												
39 Placunanomia inornata Gabb							*					
40 Psammobia hornii (Gabb)	*											
41 Semele diaboli Dickerson	*											
42 Solen parallelus Gabb	*		*		*	*	*			*		
43 Septifer dichotomus Gabb							*					
44 Thracia dilleri Dall	*		*									
45 Tellina sutterensis Dickerson	*											
46 Tellina longa Gabb												
47 Tellina hornii Gabb					*							
48 Tellina ooides? Gabb												
49 Tellina cowlitzensis Weaver												
50 Teredo sp.	*											
51 Unio transpacifica Arn & Hann	*											
52 Venericardia planicosta Gabb	*		*		*	*	*					
GASTEROPODA												
53 Amauropsis alveata Conrad	*											
54 Ancillaria bretzii Weaver	*											
55 Ambloxus olequahensis Arn & Hann												
56 Amphissa eocenica (Weaver)	*											
57 Amphissa packardi (Weaver)	*											
58 Bursa washingtoniana (Weaver)	*	*										
59 Bursa cowlitzensis (Weaver)	*											
60 Brachysphingus clarki Weaver	*					*						
61 Calyptraea excentricus Gabb	*											
62 Crepidula pilea Gabb	*											
63 Cylichna costata Gabb	*											
64 Cancellaria stantoni Dickerson	*											
65 Conus hornii Gabb	*				*							

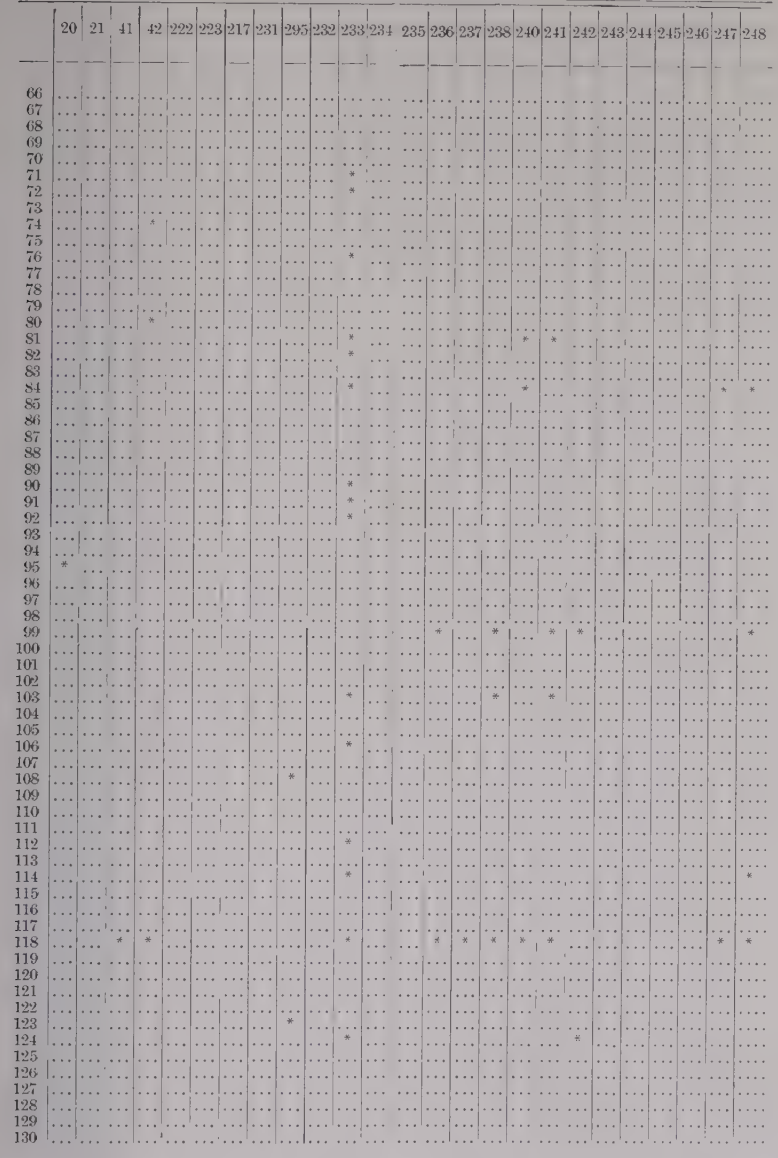
EOCENE—CONTINUED.



EOCENE—CONTINUED.

	LIST OF SPECIES	1	2	3	4	5	6	7	8	11	17	17	18
66	Conus remondi Gabb	*											
67	Conus weaveri Dickerson	*											
68	Conus cowlitzensis Dickerson	*											
69	Cantharus perrini Dickerson	*											
70	Drillia ornata Dickerson	*											
71	Exilia dickersoni (Weaver)	*											
72	Exilia lincolnesis Weaver												
73	Exilia perkinsiana (Cooper)	*				*		*					
74	Ficus mamillatus Gabb	*											
75	Fasciolaria buwaldana Dickerson	*				*	*	*					
76	Fasciolaria washingtoniana Weaver	*											
77	Fusinus lewisensis (Weaver)	*											
78	Fusinus washingtoniana (Weaver)	*											
79	Fusinus willisi Dickerson	*				*		*					*
80	Ficopsis remondi Gabb					*	*						
81	Ficopsis cowlitzensis (Weaver)	*				*		*					
82	Galeodea tuberculata (Gabb)	*											
83	Hemifusus tejonensis Weaver	*						*					
84	Hemifusus sopenahensis Weaver	*											
85	Hemifusus lewisensis Weaver	*						*					
86	Hemifusus washingtonensis Weaver	*											
87	Lunatia cowlitzensis Dickerson	*											
88	Lunatia nuciformis Gabb							*					
89	Lunatia hornii Gabb	*											
90	Mitra washingtoniana Weaver	*											
91	Murex sopenahensis Weaver	*											
92	Murex cowlitzensis Weaver	*											
93	Murex packardi Dickerson	*											
94	Melania packardi Dickerson	*											
95	Melania fettkei (Weaver)	*	*										
96	Melania lewisiana (Weaver)	*	*										
97	Melania vaderensis Dickerson	*											
98	Monodonta wattsi Dickerson	*											
99	Neverita secta Gabb	*											
100	Neverita martini Dickerson	*											
101	Nerverita weaveri Dickerson	*											
102	Nerita cowlitzensis Dickerson	*											
103	Naticina obliqua Gabb	*											
104	Nyetilochus washingtoniana (Weaver)	*											
105	Niso polito Gabb												
106	Olivella mathewsoni Gabb												
107	Olivella sp.												
108	Pachynilus drakei Arn & Hann												
109	Pseudolivia volutaeformis Gabb	*											
110	Pseudolivia inornata Dickerson	*											
111	Rimella elongata Weaver	*											
112	Rimella elongata (Weaver)	*				*							
113	Surcula washingtoniana (Weaver)	*				*							
114	Surcula cowlitzensis Weaver	*											
115	Siphonalia bicarinata Dickerson	*											
116	Turris monolifera Cooper	*											
117	Turris pulchra Dickerson	*											
118	Turritella uvasana Conrad	*				*	*	*		*			
119	Turritella sp.	*											
120	Turritella sp.	*											
121	Triforis washingtoniana Dickerson	*											
122	Urosalpinx hannibali Dickerson	*											
123	Vipiparus washingtoniana Arn & Hann												
124	Dentalium stramineum Gabb	*											
125	Cadulus pusillus (Gabb)	*											
126	Nautilus sp.	*											
127	Aturia mathewsoni Gabb	*											
128	Rhynchonella washingtoniana Weaver	*											
129	Brachyurian remains	*											
130	Fish teeth	*											

EOCENE—CONTINUED.



EOCENE—CONTINUED.

	LIST OF SPECIES	249	275	275	276	277	278	279	281	282	283
	PELECYPODA										
1	Avicula pellucida Gabb								*	*	
2	Barbatia morsei Gabb										
3	Cardium breweri Gabb						*				
4	Cardium cooperi Gabb								*		
5	Cardium olequahensis Weaver										
6	Corbula hornii Gabb										
7	Corbula n. sp.										
8	Crassatellites washingtonensis Weaver										
9	Crassatellites grandis Gabb										
10	Crassatellites merriami Weaver										
11	Crassatellites dalli Weaver										
12	Crassatellites cowlitzensis Weaver										
13	Crassatellites compacta Gabb										
14	Cyrena brevidens White	*		*				*			*
15	Corbicula cowlitzensis Weaver										
16	Corbicula eufaulaensis Weaver										
17	Diplodonta polita (Gabb)									*	
18	Glycimeris sagittata (Gabb)										
19	Glycimeris eocenica (Weaver)										
20	Glycimeris eocenica var landesi (Weaver)					*					
21	Leda vaderensis Dickerson										
22	Leda gabbi Conrad										
23	Leda sp.										
24	Meretrix hornii Gabb	*			*	*			*		
25	Meretrix uvasana Conrad										
26	Meretrix ovalis Gabb								*		
27	Meretrix olequahensis Weaver										
28	Meretrix longa? Gabb										
29	Marcia quadrata (Gabb)										
30	Marcia conradana (Gabb)									*	
31	Macrocallista andersoni Dickerson										
32	Macrocallista vaderensis Dickerson										
33	Modiolus ornatus Gabb							*			
34	Ostrea idriaensis Gabb	*			*			*	*	*	
35	Ostrea olequahensis Weaver										
36	Ostrea fettkei Weaver										
37	Pecten cowlitzensis Weaver									*	
38	Pecten landesi Arnold					*	*				
39	Placunanomia inornata Gabb										
40	Psammobia hornii (Gabb)										
41	Semele diaboli Dickerson										
42	Solen parallelus Gabb								*		
43	Septifer dichotomus Gabb								*		
44	Thracia dilleri Dall										
45	Tellina sutterensis Dickerson										
46	Tellina longa Gabb								*		
47	Tellina hornii Gabb										
48	Tellina ooides? Gabb										
49	Tellina cowlitzensis Weaver										
50	Teredo sp.										
51	Unio transpacifica Arn & Hann								*		
52	Venericardia planicosta Gabb										
	GASTEROPODA										
53	Amauropsis alveata Conrad										
54	Ancillaria bretzii Weaver										
55	Ambloxus olequahensis Arn & Hann										
56	Amphissa eocenica (Weaver)										
57	Amphissa packardi (Weaver)										
58	Bursa washingtoniana (Weaver)										
59	Bursa cowlitzensis (Weaver)								*		
60	Brachysphingus clarki Weaver								*		
61	Calyptraea excentricus Gabb								*	*	
62	Crepidula pilea Gabb										
63	Cylichna costata Gabb										
64	Cancellaria stantoni Dickerson										
65	Conus hornii Gabb										

EOCENE—CONTINUED.

	LIST OF SPECIES	249	275	275	276	277	278	279	281	282	283
66	Conus remondi Gabb										
67	Conus weaveri Dickerson										
68	Conus cowlitzensis Dickerson										
69	Cantharus perrini Dickerson										
70	Drillia ornata Dickerson										
71	Exilia dickersoni (Weaver)										
72	Exilia lincolnensis Weaver										
73	Exilia perkinsiana (Cooper)										
74	Ficus mamillatus Gabb										
75	Fasciolaria buwaldana Dickerson										
76	Fasciolaria washingtoniana Weaver										
77	Fusinus lewisensis (Weaver)										
78	Fusinus washingtoniana (Weaver)										
79	Fusinus willisi Dickerson										
80	Ficopsis remondi Gabb										
81	Ficopsis cowlitzensis (Weaver)										
82	Galeodea tuberculata (Gabb)										
83	Hemifusus tejonensis Weaver										
84	Hemifusus sopenahensis Weaver										
84	Hemifusus sopenahensis Weaver										
85	Hemifusus lewisensis Weaver										
86	Hemifusus washingtonensis Weaver										
87	Lunatia cowlitzensis Dickerson										
88	Lunatia nuciformis Gabb										
89	Lunatia hornii Gabb										
90	Mitra washingtoniana Weaver										
91	Murex sopenahensis Weaver										
92	Murex cowlitzensis Weaver										
93	Murex packardi Dickerson										
94	Melania packardi Dickerson										
95	Melania fettkei (Weaver)										
96	Melania lewisiana (Weaver)										
97	Melania vaderensis Dickerson										
98	Monodonta wattsi Dickerson										
99	Neverita secta Gabb										
100	Neverita martini Dickerson										
101	Nerverita weaveri Dickerson										
102	Nerita cowlitzensis Dickerson										
103	Naticina obliqua Gabb										
104	Nyctilochus washingtoniana (Weaver)										
105	Niso polito Gabb										
106	Olivella mathewsoni Gabb										
107	Olivella sp.										
108	Pachynilus drakei Arn & Hann										
109	Pseudolivia volutaeformis Gabb										
110	Pseudolivia inornata Dickerson										
111	Rimella simplex Gabb										
112	Rimella elongata (Weaver)										
113	Sureula washingtoniana (Weaver)										
114	Sureula cowlitzensis Weaver										
115	Siphonalia bicarinata Dickerson										
116	Turris monolifera Cooper										
117	Turris pulchra Dickerson										
118	Turritella uvasana Conrad										
119	Turritella										
120	Turritella										
121	Triforis washingtoniana Dickerson										
122	Urosalpinx hannibali Dickerson										
123	Vipiparus washingtonians Arn & Hann										
124	Dentalium stramineum Gabb										
125	Cadulus pusillus (Gabb)										
126	Nautilus sp.										
127	Aturia mathewsoni Gabb										
128	Rhynchonella washingtoniana Weaver										
129	Brachyuran remains										
130	Fish teeth										

Marine invertebrate Tejon fossils are confined entirely to the western part of the state. None occur in the Swauk or Roslyn formations of the central Cascades. Fossil plant remains occur both in the fresh water and estuarine deposits. In many cases the plant bearing estuarine beds are interbedded with the marine strata. Such evidence indicates that the fossil plants of the western portion of the state are of the same age as the marine invertebrates, namely upper Eocene. Insufficient work has been done on the fossil flora of the lacustrine beds of the Cascades to show their relations to the fossil flora west of the Cascades.

Near Duwamish Station, south of Seattle, marine beds containing marine invertebrate fossils occur associated with the lignite bearing strata which are the equivalent of the coal bearing strata of New Castle and Renton. Presumably the estuarine beds of King and Pierce counties are of Tejon or upper Eocene age.

The upper Eocene marine faunas of western Washington show close similarities at all localities. Marine and estaurine strata are interbedded but the former occur near the base as well as at the top of the series. At the present time there seems to be no sufficient evidence to warrant subdividing the Tejon into formations. Several faunal zones may ultimately be recognized. In the type section between Olequa and Winlock the marine faunas have their closest relationship to the Siphonalia suterensis Zone of the Tejon of California.*

The fossil flora varies somewhat at different localities but the stratigraphic relations in those localities where collections have been made are not in all cases known. A large number of the species are new and undescribed and their range unknown.

CONDITIONS OF DEPOSITION.

The bathymetric conditions under which the upper Eocene deposits of western Washington accumulated ranged from very shallow depths in the estuarine basins to possibly a maximum

* Dickerson, Roy E., Fauna of the Eocene at Marysville Buttes, California, Univ. Calif. Publ. Bull. Dept. Geol. vol. 7, pp. 257-298, p. 13, 11-14, 1913.

depth of 100 fathoms. Corals are unknown as fossils in these deposits. Glauconite which is common in portions of the Eocene of California has not been recognized in the Eocene of Washington. The majority of the genera belonging to the Pelecypoda and Gasteropoda are forms whose environment is in the littoral or sublittoral zones. Differential subsidence and elevation characterized the sea floor during the Tejon epoch. In those portions of King, Pierce and Lewis counties where estuarine conditions prevailed oscillations of the embayment floors must have been frequent. Over 100 coal or carbonaceous seams are interstratified with sandstone and shale members and each represents an interval of time during which vegetation flourished under possible swampy conditions. The sandstones or shales above each seam are water laid and indicate subsidence and a burial of the former swamp areas. Wherever the strata contain marine fossils there is evidence that the subsidence has been sufficiently great to cause the marine waters to transgress over former estuaries.

The arkosic character of many of the massive sandstone members in King and Pierce counties indicates nearby land areas composed largely of granitic or dioritic rocks which were being vigorously subjected to erosion. Presumably portions of the Index, Mt. Stuart and Snoqualmie granodiorites were in part supplying this material. Many of the clay shales show ripple marks indicating the presence of extensive tidal flats presumably situated near the shores of the estuaries. The simultaneous outpouring of lavas and the deposition of volcanic tuffs have already been referred to.

CLIMATIC CONDITIONS.

The climate of the Eocene in Washington as well as in California and Oregon was tropical. The marine invertebrates belong to genera which are found for the most part at the present time in the waters of the tropics. The fossil flora tells the same story. Palms and other closely allied groups predominate. In the upper beds of King and Pierce counties as well as in the

Olequa-Winlock region the flora indicates the presence of species of sycamores and birches. Apparently towards the close of the Tejon epoch the climate became somewhat cooler and certain austral types of plants began to develop. This climatic change is evidenced in the flora rather than in the fauna.

NEWCASTLE HILLS—GRAND RIDGE AREA.

GEOGRAPHIC DISTRIBUTION.

The Newcastle Hills are the westerly extension of a spur from the Cascade Mountains, situated between Snoqualmie Valley on the north and Cedar River on the south. They range in elevation from 3,000 feet, south of Grand Ridge, to sea level at Lake Washington. Both Eocene and Miocene formations occur within them. The Eocene, consisting of both sedimentary and volcanic rocks, occupies an area about two miles in width near Lake Washington, but increases easterly in the vicinity of Grand Ridge to over four miles. This belt of outcrops trends approximately east and west. The western end swings slightly to the northwest and the eastern end to the northeast in the vicinity of Grand Ridge.

CHARACTER OF OUTCROPS.

To the north of, and fringing the belt of Eocene outcrops just described, are marine sediments of Oligocene age. To the north of these, for a distance of over fifteen miles, no outcrops of formations older than Pleistocene glacial drift deposits are known to appear at the surface at any locality. Bed rock undoubtedly exists at various depths below the thick covering of glacial drift. Glacial drift of varying thickness mantles the Newcastle Hills, but in many places it has been removed by erosion exposing bold outcrops of bed rock such as Squak Mountain and Tiger Mountain immediately east of Issaquah Creek. The hills just north of May Creek are somewhat rugged and show the effects of glacial scouring.

LITHOLOGY.

The Eocene formation in the Newcastle Hills is composed of sedimentary and igneous rocks, the former resting strati-

Interbedded Tuffs and Shale in the Eocene Basalt Series at Port Crescent, Washington.

graphically above the latter. The sedimentary division is composed of coarse grained sandstones, shales, sandy shales, shaly sandstones, and carbonaceous seams. These several phases of the formation vary in thickness and are interbedded with one another. The sandstones are commonly coarse grained and appear to be largely composed of materials derived in part from volcanic lavas and tuffs and in part from granite and granodiorite. Cross-bedding is generally very pronounced in this phase of the formation. Often small seams of a chocolate-brown colored very fine grained shale occur interbedded in the form of lenses within the sandstone. Near the upper and lower portions of the thicker beds of sandstone at the contacts with the shale bands there are commonly very thin layers of shale less than one inch in thickness interbedded with narrow seams of sandstone averaging less than one-half inch in thickness, giving this type of rock a banded or laminated appearance. The sandstone masses are sometimes as much as one hundred and fifty feet in thickness. The shales are commonly massive without very distinct bedding planes. They break with a conchoidal fracture and occasionally possess considerable thickness. The sandy shales and shaly sandstones are generally harder and possess well-defined bedding planes. Within these are often found remains of fossil leaves, especially in the vicinity of the carbonaceous seams.

In the Coal Creek mine hundreds of fossil trees occur standing at right angles to the bedding planes of the coal seams and projecting upwards into the shales and sandstones above. Many of these trees have a diameter of four or five feet.

The strata outcropping along Coal Creek and in the underground workings of the Coal Creek mines are lithologically very similar to those on Tibbetts Creek in Section 32, and to those at Issaquah in Sections 26 and 33. Some minor variations, however, may be noted along the strike of individual beds or coal seams, as in the case of the Bagley coal seam in the Coal Creek mine.

The belt of igneous rock which underlies the sedimentary phase of the Eocene is composed of a series of lava flows with interbedded volcanic tuffs apparently derived from small fissures and vents in the immediate vicinity. None of this material, however, is found interbedded with the sedimentary portions of the formation above. The base of the sedimentary formation is composed of conglomerates made up of pebbles and boulders firmly cemented and derived directly from the various phases of this lava and tuff. A careful examination of the lava areas along the anticlinal belt shows the presence of much intrusive material of the same nature indicating that vents were continuously being opened through the earlier consolidated portions of the flow, allowing fresh material to well out over the surface. Many of these flows show the effects of movement just prior to consolidation and contain irregular shaped angular blocks of hardened lava which they have carried along with them. The tuff beds contain various sized fragments of pumice which have been firmly indurated. Some phases of the lava are very porphyritic showing large crystals of feldspar imbedded in a fine grained groundmass. Other phases possess a distinctly fine grained basaltic appearance; some individual flows are completely honeycombed with steam cavities.

GEOLOGIC STRUCTURE.

The principal structural feature of the Newcastle-Issaquah area is a broad anticline trending along the direction of the Newcastle Hills. Between lakes Washington and Sammamish it trends North 45° West. In the vicinity of the town of Issaquah and Squak Mountain it trends nearly east and west and then turns North 45° East in the vicinity of Grand Ridge. The north limb of the anticline between the Newcastle Hills and Grand Ridge develops into a broad syncline the axis of which trends nearly due north through Lake Sammamish. The western extension of the anticline can be traced to the eastern shores of Lake Washington in the vicinity of Newcastle Landing. From Newcastle Landing it crosses Lake Washington and passes through the south central part of Mercer Island. This

island is almost entirely composed of glacial drift, but on its western side in Section 24, Township 24 North, Range 4 East, huge broken boulders of basic igneous rock outcrop at the water's edge, which may possibly be a part of the core of the anticline. Immediately west on the Bailey Peninsula and just south toward Brighton Beach well defined outcrops of Oligocene shales and sandstones outcrop. These strata have a northeast-southwest strike with a very steep dip to the north. They are a continuation of similar strata occurring in the Newcastle Hills just north of Coal Creek. This, together with further evidence in the Rainier and Duwamish valleys, show conclusively that the anticline occurring in the Newcastle Hills crosses Lake Washington and then turns south toward Duwamish Station.

Along the course of Coal Creek from its mouth to its headwaters, numerous outcrops occur upon which observations for strike and dip can be obtained. These show the strike to range from North 45° West to North 70° West, the latter prevailing near the headwaters of the creek at the town of Coal Creek. The dips range between 40° and 70°. The general average is between 45° and 50° to the northeast. Similar observations were taken farther to the northeast along logging and wagon road cuts in the overlying Oligocene formations. From Coal Creek these same strata cross the mountain ridge and reappear on the north slope of Squak Mountain between Tibbetts and Issaquah creeks. Excellent observations on strike and dip may be taken in the vicinity of the Superior Coal Mine on Tibbetts Creek in Section 32, Township 24 North, Range 6 East and also in Section 33, same township and range, in the vicinity of the Issaquah coal mine at the town of Issaquah. The strike in both of these localities is nearly east and west with an average dip of 40° to the north. In the vicinity of Grand Ridge in Section 26 the strike swings to the northeast. Numerous observations were recorded both on the surface and in the underground workings of the Grand Ridge Mine. About two miles northeast of Grand Ridge in Section 13, Township 24 North, Range 6

East, several openings have been made in the bed rock strata along the courses of small creeks, exposing coal seams as well as sandstone and shale strata. The strike averages North 45° East with a dip of 65° to the northwest.

To the north and east of these outcrops the Eocene rocks are no longer exposed, but are covered with a very thick mantle of glacial drift. About four miles southeast of Section 13, in Section 28, Township 24 North, Range 7 East, outcrops of sandstone and shale are exposed in a railroad cut just west of the point where the Northern Pacific railway crosses Raging River. The strike of these beds is North 45° West and the dip ranges between 55° and 75° to the northeast. Although there is no absolute certainty that these are a continuation of the exposures in Section 13, yet it is probable that they are such an extension and are a part of the north limb of the Newcastle Hills anticline. The main axis of the anticline has been indicated upon Map B, Plate IV, and consists of almost continuous outcrops of basaltic lavas and tuff lying stratigraphically below the Eocene sandstones and shales.

From such evidence as can be obtained on May Creek along the south side of this anticline, the probabilities are very strong that the strata on the north slope formerly arched over the lava and dipping southward, extended under what is now May Creek Valley. The evidence pointing toward this conclusion may be found in Section 2, Township 23 North, Range 5 East, along the May Creek wagon road. Several exposures of sandstone and shale appear on the north side of May Creek close to the wagon road and near the surface are dipping almost vertical with a strike of North 75° West which is approximately parallel to the anticlinal axis just described. At this point on May Creek, a seam of coal has been discovered and a shaft sunk upon it to a depth of 325 feet. At the foot of the shaft a crosscut has been driven to the south for a distance of 450 feet. Along this crosscut several seams of coal were encountered as well as sandstone and shale strata which lithologically resemble very closely those in the Coal Creek and Newcastle mines on the

north side of the anticline. At the depth of the crosscut below the surface the strata are no longer pitching vertical, but assume a dip of 64° to the southwest. Outcrops of sandstone and shale on the south side of the anticline are only known in sections 1 and 2. To the west, toward Lake Washington, the country is almost entirely covered with deposits of glacial drift and the only pre-glacial outcrops exposed at the surface are occasional masses of basaltic lava and tuff. To the east of sections 1 and 2 no sedimentary rocks are exposed for a distance of six miles. Throughout this distance the south limit of the lavas which is indicated upon Map B, Plate IV, is in direct contact with very thick deposits of glacial drift. In Sections 12 and 13, Township 23 North, Range 6 East, numerous exposures of Eocene sandstones and shales containing coal may be seen along one of the branches of Issaquah Creek. This belt is about one-third mile in width and two miles in length. On both the northwest and southeast sides of this small belt are large areas of andesitic lava which should stratigraphically underlie the sediments. These sediments are presumably a remnant of those which at one time arched the anticline and have been dropped into their present position as a fault block.

The vertical and even overturned position of the strata along May Creek strongly suggests a slightly overturned anticline and also a possible fault approximately parallel to the strike. Along the sedimentary igneous contact in a number of places as may be seen near the May Creek coal shaft there are slickensided walls on the lava. If such a fault exists it quite possibly extends southeasterly into the Sherwood-Taylor region which will be described later.

From May Creek southward to Cedar Creek no outcrops of Eocene strata have been found to indicate the intervening structure. The northward pitching attitude of the strata at Renton and Cedar Mountain suggests a possible synclinal basin of Eocene strata trending parallel to and lying between Cedar River and May Creek.

STRATIGRAPHY.

The following stratigraphic section was measured from the base of the coal series on Coal Creek to the top of the productive coal measures. Unmeasured Eocene strata extend above this.

Top of Section	*Feet*
Massive brownish gray sandstone and interbedded shales	3004
Banded gray shale	25
Massive brown sandstone	115
Coal seam	8
Massive brownish gray sandstone	54
Dark gray shale	5
Banded shale	21
Light gray coarse sandstone	10
Thick bedded gray shale	28
Coal seam	17
Shale	9
Coal	1
Light gray sandstone	67
Gray shale	6
Gray sandstone	17
Dark gray shale	4
Massive brown sandstone	10
Clay	3
Massive brown sandstone	13
Banded shale and sandstone	37
Black shale	8
Coal and shale bands	25
Shale	3
Massive brownish gray sandstone	38
Dark gray shale	13
Coal seam	6
Sandy clay	9
Banded sandstone	17
Banded shale	36
Coal	14
Dark gray shale	8
Coarse brownish gray sandstone	36
Massive gray shale	14
Coal	17
Massive sandstone	4
Sandy shale	23
Sandstone	9
Interbedded sandstone and shale	8
Coarse brownish gray sandstone	19
Gray shale	30
Coal seam	20
Massive brownish gray sandstone	50
Coal seam	6
Massive brownish gray sandstone	9
Shaly sandstone	13
Massive brownish gray sandstone	126
Coal seam	10
Massive brownish gray coarse grained sandstone	30
Base of Section	
Total	4055

GREEN RIVER AREA.

GEOGRAPHIC DISTRIBUTION.

The region involved in this area comprises nearly all of Township 21 North, Range 7 East, the eastern half of Township 21 North, Range 6 East, the south half of Township 22 North, Range 7 East and the southeastern quarter of Township 22 North, Range 6 East. This territory is drained by Green River in the central portion, Cedar River on the north, and White River on the south. It extends easterly to the foothills of the Cascades and includes the low glacial hills of the east part of the Puget Sound Basin. In places the glacial covering has been in part removed by erosion and the underlying Eocene sandstones and shales exposed. The most extensive outrops are along the canyon of Green River and in the smaller streams emptying into it. Tiger Mountain at Bayne and Sugar Loaf Mountain near Durham are bedrock hills of sandstone surrounded by deposits of drift. At the eastern margin of the region the Eocene sedimentaries pass beneath the Miocene and Pliocene lavas and tuffs. The contact roughly follows the western escarpment of the foothills of the Cascade Mountains.

LITHOLOGY.

The Eocene formation exposed within this area is almost exclusively of sedimentary origin. Minor amounts of igneous material occur in the form of dikes and sills which are probably post-Eocene in origin. They may have been feeders to the Enumclaw lavas which undoubtedly at a former time covered this area.

The sedimentaries consist of sandstones and shales of varying characteristics. The sandstones are usually massive and thick bedded with a brownish gray color when fresh. Often they exhibit cross-bedding. Certain phases are very coarse grained and arkosic. One of these beds, as exposed near Franklin in the canyon of Green River, is almost 600 feet in thickness and is persistent in lithologic character throughout this area. This belt is medium grained and hard. When weathered it assumes a

light brown color and forms almost vertical canyon walls. These massive sandstones occasionally pass into shaly sandstones and from that condition into sandy shales. The shales range from a dark gray to a brown and from a massive condition to a distinctly laminated phase. Narrow bands of all these types occur interbedded with one another. All phases may be seen in the exposures along Green River.

Interbedded with this series of sediments are numerous coal seams and carbonaceous shale beds. They vary in thickness from a few inches to fifty feet. The character of the coal ranges from a bituminous to a low grade lignite. Within each seam there are variations in character from the base to the top. The different lithologic members of the formation including the carbonaceous seams often change in composition when followed along the strike of the beds indicating different conditions on the sea bottom at the time of their deposition.

The intrusive dikes and sills are narrow and usually intercalated with the sedimentary beds. They range from a foot to 80 feet in thickness. When fresh specimens can be obtained they are found to be very fine grained and composed of labradorite feldspar and augite. The minerals are always more or less altered and the phenocrysts are only slightly larger than the microlites of the ground mass. The rock would be classed as a basic andesite.

Twelve of these dikes occur in the canyon of Green River between Kummer and Palmer Junction. Six others are on Coal Creek south of Bayne. One of the largest dikes occurs in the western half of Sections 18 and 19, Township 21 North, Range 7 East. It crosses the Columbia and Puget Sound R. R. near the center of Section 18 and trends nearly due north for a distance of one mile. It is overlain and underlain with Eocene shales and pitches with them to the west at an angle of 40°.

STRATIGRAPHY.

The excellent exposures of the Eocene formation in the canyon of Green River afford opportunities for constructing stratigraphic sections of the series. In the underground workings of

the coal mines as well as at many localities both to the north and south of Green River partial sections may be measured which in many cases can be directly referred to their true position within the complete section as exposed along Green River. As a result of such field studies it is possible to subdivide the Green River Eocene into three lithologic units. The terms Bayne, Franklin and Kummer series have been applied. These subdivisions can be recognized only locally and cannot be used for lithologic correlation purposes. For this reason it would seem best to regard them as members and not formations. Detailed surveys have been made in Green River canyon and the lithologic variations from the base to top of each member have been determined.

The lowest division, or Bayne member, consists of a predominating series of shales together with subordinate amounts of sandstone, shaly sandstone and carbonaceous beds. It has a thickness of over 3,000 feet as measured along the canyon of Green River from the center of Section 17 up the river to the east line of Section 8, Township 21 North, Range 7 East. The top of this member appears at the Franklin wagon bridge at the contact with the Franklin sandstone member. The following section was in part measured by the writer in connection with an investigation of the King County coal fields:

STRATIGRAPHIC SECTION OF BAYNE MEMBER.

Top of Section.	*Feet*
Brownish gray sandstone, somewhat banded	135
Gray sandy shale	14
Coal and carbonaceous material	35
Gray sandy shale	19
Covered	40
Alternating beds of shale carbonaceous shale and sandy shale.	128
Massive grayish brown sandstone	52
Interbedded sandy shales and carbonaceous seams	30
Massive brownish gray coarse grained sandstone	45
Carbonaceous seam	7
Gray sandy shale	27
Carbonaceous seam	9
Alternating beds of sandy shale and carbonaceous seams	55
Sandy shale	82
Brownish gray banded sandstone	22
Gray sandy shale	51
Carbonaceous seam	34
Sandy shale	24

Top of Section.	*Feet*
Massive brownish gray sandstone	11
Gray banded sandy shale	30
Massive brownish gray coarse grained sandstone	21
Shale and carbonaceous seams	26
Massive brownish gray sandstone	10
Interbedded banded gray shale and carbonaceous seams	81
Massive grayish brown coarse grained sandstone	85
Interbedded shaly sandstone and carbonaceous seams	22
Massive brownish gray coarse grained sandstone	120
Sandy shale and carbonaceous seams	26
Coarse massive brownish gray sandstone	117
Banded gray sandy shale	50
Carbonaceous seam	40
Banded sandy shale	16
Brownish gray coarse grained sandstone	40
Interbedded sandy shale and carbonaceous seams	106
Massive brownish gray coarse grained sandstone	190
Carbonaceous seam and sandy shale	30
Massive brownish gray sandstone	94
Stratified sandy shale	44
Massive brownish gray sandstone	60
Interbedded sandy shale and carbonaceous seams	43
Massive brownish gray coarse grained sandstone	123
Banded sandy shale and carbonaceous seams	157
Banded gray sandstone	83
Interbedded shale, sandy shales and coal seams	246
Massive brownish gray sandstones	55
Coal seam	6
Brown gray banded sandstone	27
Coal seam	5
Massive gray sandstone	21
Banded gray sandy shale	11
Banded gray sandstone	29
Interbedded gray shale and carbonaceous seams	30
Brownish gray sandstone	13
Carbonaceous seam	5
Massive brownish gray sandstone	35
Slightly metamorphosed sandstone	21
Andesite and baked sandstone	26
Massive but somewhat baked sandstone	45
Base of Section	
Total	3009

The Franklin member is composed of massive sandstones with interbedded shales and carbonaceous seams possessing a thickness of over thirty-six hundred feet. The basal portion of the series consists of a belt of massive coarse grained brownish gray sandstone having a thickness of 600 feet. It is typically exposed at the Franklin bridge. The upper portion of the Franklin series contains the most important seams of coal mined in the district. The following stratigraphic measurements of this series have been made:

Stratigraphic Section of Franklin Member as measured on Green River, King County.

	Feet
Bony coal	16
Stratified sandy shale	20
Shaly gray sandstone	52
Inter-stratified shale and carbonaceous shale	9
Brown massive sandstone	7
Gray shale	8
Hard shaly carbonaceous bed	6
Nodular sandy shale	4
Interbedded shale and carbonaceous shale	37
Laminated sandstone	10
Nodular gray shale	5
Banded gray sandstone	22
Banded gray sandy shale	13
Banded gray shale	10
Carbonaceous seam	10
Carbonaceous shale	12
Banded sandy shale	30
Massive brownish gray sandstone	23
Carbonaceous shale	15
Massive sandstone	6
Nodular gray shale	7
Banded gray sandstone	30
Light-brown medium-grained sandstone	150
Massive brownish gray sandstone	205
Covered	204
Massive gray sandstone	58
Intrusive sill of andesite	10
Carbonaceous seam	13
Banded nodular gray shale	6
Interbedded carbonaceous seams and shale	24
Banded gray sandy shale	15
Brownish gray massive sandstone	23
Banded gray sandy shale	12
Carbonaceous seam and shale	17
Massive brownish gray medium-grained sandstone	83
Interbedded sandy and carbonaceous shale	25
Massive brownish gray sandstone	74
Carbonaceous seam	2
Massive brownish gray sandstone	3
Gray shale	17
Carbonaceous shale	6
Banded gray shale	5
Massive brownish gray sandstone	6
Banded gray sandy shale	23
Carbonaceous shale	6
Massive brownish gray sandstone	13
Banded gray sandy shale	45
Brownish gray massive sandstone	92
Banded brownish gray sandstone	12
Banded gray shale	11
Intrusive sill of andesite	10
Covered	35
Massive brownish gray sandstone	24
Banded brownish gray sandstone	17
Banded gray sandy shale	12
Covered	37

	Feet
Banded brownish gray sandstone	12
Covered	24
Banded brownish gray sandstone	20
Banded gray sandy shale	30
Covered	20
Banded gray sandstone	26
Banded gray sandy shale	58
Gray sandy shale	18
Banded gray sandstone	28
Banded sandy shale	16
Coal seam	11
Interbedded layers of shale, sandy shale, carbonaceous seams and thin bands of shaly sandstone	191
Massive brownish gray sandstone	26
Banded gray sandy shale	7
Medium grained brownish gray sandstone	44
Coal seam	7
Banded nodular gray sandy shale	58
Carbonaceous bed	38
Gray shaly sandstone	8
Massive gray brownish sandstone	25
Interbedded sandy shale and shaly sandstone	79
Gray banded sandy shale	78
Intrusive sill of andesite	7
Slightly metamorphosed shale	32
Intrusive sill of badly altered andesite	118
Banded gray sandy shale	35
Banded brownish gray sandstone	24
Banded sandy shale	10
Banded brownish gray sandstone	16
Massive brownish gray sandstone	37
Banded gray sandy shale	23
Interbedded carbonaceous seam with sandy shales	78
Banded gray sandy shale	14
Massive brownish gray sandstone	46
Carbonaceous seam	10
Banded gray sandy shale	30
Covered	22
Carbonaceous seam	5
Banded gray sandy shale	23
Covered	47
Massive brownish gray sandstone	44
Carbonaceous seam	6
Banded gray sandy shale	15
Banded brownish gray sandstone with interbedded layers of shaly sandstone	119
Covered	107
Banded gray sandy shale	10
Franklin sandstone light grayish brown color and medium grained	210
Base	
Total	3358

The uppermost division of the Eocene sedimentaries as exposed in Green River canyon consists of a predominating series

of coarse grained light colored sandstones together with numerous intercalated strata of shale and carbonaceous beds. They possess a thickness of about 1800 feet and are described as the Kummer member. At the base of this series there is a light colored massive sandstone having a thickness of 475 feet. The entire Kummer member is involved in a syncline with the basal sandstone of the western limb resting in the eastern half of Section 26, Township 21 North, Range 6 East. The following stratigraphic section has been measured:

Stratigraphic Section of the Kummer Member.

Top of Section	*Feet*
Banded sandstone	10
Alternating beds of shale, sandy shale and carbonaceous seams	91
Massive, brown, coarse grained sandstone	540
Covered	35
Coal	2
Massive, brown, coarse grained sandstone	30
Dark gray shaly sandstone	12
Massive, brown, medium grained sandstone	100
Coal and carbonaceous shales	8
Gray sandy shale	60
Gray shale	113
Coal seam	2
Massive brown gray coarse grained sandstone	165
Coal seam	3
Shale	30
Coal seam	5
Dark gray shale	55
Coal seam	4
Brownish gray sandstone	7
Fire clay	5
Coal seam	6
Massive brownish gray coarse grained sandstone	475
Base of Section	
Total	1758

No strata of purely marine origin have been found in the Green River area. In the Bayne member, species of brackish water mollusca are occasionally found. They are in a bad state of preservation but belong mostly to the genus *Corbicula*. No subdivisions of the Green River Eocene can be formed on a basis of the brackish water molluscan fauna. The species occurring here are common in all the brackish water zones interbedded with the marine Tejon occurring farther to the southwest. Fossil plant remains are abundant at many localities along Green River but there is insufficient knowledge con-

cerning the species to warrant using them for correlation purposes.

GEOLOGIC STRUCTURE.

The geologic structure of this area is very complex. Detailed traverses tied in by transit surveys were made along Green River from Section 28, Township 21 North, Range 6 East to Section 13, Township 21 North, Range 7 East, a distance of over seventeen miles. Stratigraphic sections were made throughout this entire traverse. All the variations in strike and dip were recorded in their exact position along this traverse line. This line and all observations tied into it have been platted and may be referred to in the report on the King County coal fields.*

Observations on the strikes and dips have been taken at all points where outcrops were found to occur, either above or below ground. From the results of such data it has been possible to determine the approximate structure which the Eocene sedimentary formations now assume.

The broad general features of the structure consist of a series of nearly parallel anticlines and synclines pitching to the south. Their average trend is North 20° East. One broad syncline begins on the boundary line between Ranges 6 and 7, Township 21 North, in the vicinity of Sections 7 and 12. This syncline averages about two miles in width and at least six miles in length. At least six parallel anticlines and as many synclines lie on the east side. One anticline and one syncline lie on the west. What the structure may be beyond, to the west, cannot be determined because of the absolute disappearance of the Eocene formations beneath a very thick covering of glacial drift. These anticlines and synclines in the vicinity of Cedar River, to the north, also disappear below a very thick covering of drift and only reappear in the vicinity of Taylor and Raging River.

* A part of the work was undertaken by the writer during the season of 1909 and the details are to be found in the maps accompanying a report on the coal field of King County, Bulletin No. 3, Washington Geol. Survey 1912.

In addition to folding, the strata have been cut by numerous faults, the most prominent of which trends in a sinuous manner nearly east and west and has dislocated the strata nearly at right angles to their strike. This fault appears to begin in Section 21 and to extend westerly through Sections 20 and 19 of Township 21 North, Range 7 East, into Sections 24, 13, 14 and 15 of the township immediately west. The dislocation along this fault plane has been definitely shown in the underground workings of the Franklin mine and in the dislocated positions of the big heavy massive Franklin sandstone adjacent to the fault plane. Numerous minor faults occur in this region.

CONDITIONS OF DEPOSITION.

The Eocene sedimentaries of the Green River area as well as those in the Pierce County coal field are of shallow water origin. They were deposited in an estuarine basin which during the progress of Eocene time was in a state of differential oscillation. The results of these diastrophic movements are to be observed in the alternating character of the sediments and in the numerous interbedded coal seams. Some of the lower grade seams attain a thickness as great as fifty feet.

CEDAR MOUNTAIN AREA.

GEOGRAPHIC DISTRIBUTION.

This area is situated within Cedar River Valley in Sections 29 and 30, Township 23 North, Range 6 East. The surrounding country is very heavily covered with glacial drift. Three miles to the north, the basalts of the Newcastle anticline outcrop and five miles to the west the Renton coal measures appear. Exposures of this formation are well developed in the banks of Cedar River in Section 29. In Section 30 the strata are well developed along the county road and in the hill just south. A number of coal seams occur interbedded with sandstones and shales and these have been opened up by a series of underground tunnels.

STRATIGRAPHY.

The Eocene formations in this region are composed almost entirely of sedimentary rocks, consisting of sandstones, shales and carbonaceous beds. The total thickness of the strata as measured upon the surface is over two thousand feet. The lower eight hundred feet of the section contain the coal seams. The upper half of the section is predominantly shaly. The section as a whole is lithologically somewhat similar to that exposed at Renton. The following stratigraphic section has been measured:

Stratigraphic section as measured at Cedar Mountain along county road.

Top of Section	*Feet*
Banded gray shales	120
Brown concretionary shale	570
Interbedded shale and sandy shale	400
Brown sandstone	8
Interbedded sandstone and shale	30
Banded sandstone and shale	82
Coal	12
Light gray massive sandstone	45
Covered	18
Banded sandy shale	60
Covered	62
Banded brownish gray shale	28
Brownish gray coarse grained sandstone	23
Banded brownish gray shale	12
Massive brownish gray sandstone	22
Total	1492

GEOLOGIC STRUCTURE.

In Section 20, Township 23 North, Range 6 East, the strata have a strike of North 20° West and dip to the northeast. In this particular locality they may represent the southwest limb of a syncline whose axis lies somewhere southwest of May Creek and trends northwest to southeast. If so, the north limb of the syncline should reach the surface along the valley of May Creek.

South from Section 20 at Cedar Mountain the strike swings and becomes more nearly north and south and in Section 30 becomes North 45° East with a southeasterly dip. The strata of Cedar Mountain are possibly involved in the nose of a southeasterly pitching anticline, and are more or less dislocated by faulting.

RAGING RIVER AREA.

GEOGRAPHIC DISTRIBUTION.

Eocene deposits occurring within this area are confined almost entirely to Township 23 North, Range 7 East and the north half of Township 22 North, Range 7 East. Raging River Valley heads in the southern part of Township 23 North, Range 7 East and extends nearly due north to the valley of Snoqualmie River. A few surface exposures of sandstones and shales occur but the greater part of the area is deeply covered with glacial sand and gravels. The rock outcrops are confined chiefly to the small canyons along the valley slopes. The floor of the valley is entirely covered with drift. Elevations in this region range from 1,000 to 3,500 feet. The entire area is covered with a dense growth of forest and underbrush.

STRATIGRAPHY.

Exposures of Eocene rocks occur as a rule in small disconnected patches rendering it difficult to determine the relation of one outcrop to another. Sandstones and shales outcrop in the beds of the creeks west of Raging River between Preston and Kerriston. Low grade coal and carbonaceous bands are interbedded with the sediments and several years ago were prospected. All of these materials have been invaded by dikes of andesite and rhyolite. Nearly all the coal seams are more or less disrupted and in places baked. Such exposures as occur along the divide between Raging River and Issaquah Creek are composed of a brownish yellow badly altered igneous rock. Some of the fresher specimens upon examination are found to be a rhyolite intrusive. To the north of Taylor the dikes are andesitic in character. It is possible that these intrusives may be in part contemporaneous with the Eocene deposits but presumably the greater proportion of such outcrops are a part of the igneous materials which were intruded in the near vicinity during the upper Miocene or lower Pliocene. The greater portion of the ridge between Raging and Snoqualmie valleys is composed of andesite and tuffs belonging to the Enumclaw Volcanic Series. These lavas cover extensive areas from the foot-

hills of the Cascades to the summit of the range. It is quite possible that these dikes are remnants of feeders to these late Miocene flows.

The sandstones are brownish gray in color, medium grained and in places cross bedded. The shales grade from a clayey condition to a banded sandy shale. They are best exposed in Sections 9, 16, 21 and 26. They also outcrop in Sections 32 and 33 and continue into the township immediately south where they are well developed in the vicinity of the Taylor coal mine in Sections 2, 4 and 5. Shales and sandstones with interbedded coal seams occur on the divide between Snoqualmie and Raging River valleys in Sections 1 and 12, Township 23 North, Range 7 East. No very detailed stratigraphic sections can be measured with the exception of those exposures occurring within the Taylor mine. In the main crosscut tunnel of the mine a cross-section of the strata is as follows:

Top	*Feet*
Massive coarse grained sandstone	92
Coal seam	10
Hard gray clay shale	2
Massive shaly sandstone	63
Carbonaceous sandy shale	3
Hard massive sandy shale	27
Coal seam	7
Massive sandstone	5
Coal seam number seven	55
Shale	3
Massive coarse grained sandstone	187
Sandy shale	3
Igneous dike	6
Carbonaceous seam	2
Igneous dike	2
Coal seam	21
Shale	91
Coal seam	13
Shale containing brackish water fossils	23
Coal seam	12
Brown shale	8
Hard massive sandstone	8
Banded sandy shale	50
Light colored plastic clay	10
Dark gray shale	6
Coal seam, cut by igneous dike	11
Light gray massive sandstone	143
Coal seam	36
Dark gray shale	16
Coal seam	24

Top	*Feet*
Massive sandstone	95
Dark gray shale	1
Massive sandstone	2
Coal seam	4
Igneous dike	22
Shaly sandstone	23
Coal seam	9
Massive dark gray sandy shale	10
Banded sandy shale	6
Massive sandy shale	37
Shale	11
Sandy shale	12
Carbonaceous seam	10
Sandy shale	7
Massive shaly sandstone	9
Massive gray shale	2
Thinly bedded shale	7
Massive gray shale	6
Thinly bedded shale	12
Shale	15
Massive sandy shale	175
Total	1414

The sedimentary strata are of brackish water origin. No marine fossils are known. The most common species are *Batissa newberryi* White, *Cyrena brevidens* White and *Corbicula puget-ensis* White. These species are characteristic of the estuarine Eocene of western Washington but give no clue as to what particular portion of the upper Eocene they represent.

GEOLOGIC STRUCTURE.

The well defined anticline extending easterly from Lake Washington past Issaquah to Grand Ridge apparently flattens out in the region between Issaquah and Taylor and develops into a complex series of small anticlines and synclines. This complex folding has been further complicated by much faulting and the strata have been badly dislocated as the result of numerous igneous intrusions. In Township 23 North, Range 7 East, the strata have been so badly disrupted as to make it impossible to determine any well defined structure. The western limb of an anticlinal axis appears to trend about North 35 West through Sections 22, 16, 9, 8, 5 and 6. Numerous strikes and dips have been recorded; many of them are at variance with one another, but the majority of those taken on

outcrops that appear to be least disturbed, possess a southwesterly dip averaging 35°. To the west of the sedimentary outcrops just mentioned, the only pre-glacial formations exposed are a few scattered outcrops of badly altered igneous rocks occurring in Sections 17, 18, 19 and 20. The areal distribution of these has been indicated upon the accompanying map and while no definite statement can be made, yet the relations of the sedimentaries to the igneous suggest a fault trending North 15° West. If such a fault exists the sediments along the western slope of Raging River Valley have been dropped down to the northeast. The central portion of Raging River Valley contains no outcrops. It is deeply filled with deposits of glacial drift. In Sections 1 and 12 in the northeast corner of Township 23 North, Range 7 East, the Eocene sediments have a prevailing strike of North 35 West and a dip of 62° to the southwest. They are isolated from any of the surrounding outcrops and may possibly represent the western limb of a second anticline lying parallel to, and to the northeast of, the one previously mentioned in Sections 9, 16 and 22. If so, a broad synclinal trough must lie along the present position of Raging River or a little to the east of it. The strata as exposed in the underground mine workings in Sections 1 and 12 are badly dislocated as the result of faulting.

In the southeastern corner of Township 23 North, Range 7 East, a number of rock exposures outcrop in Section 26, about one-half mile west of Kerriston. These strata assume a nearly east-west strike with an average dip of about 46° to the south. They are presumably a part of the southwestern flank of the anticline referred to as trending through Sections 16, 21 and 22 on the west side of Raging River.

In Sections 2, 3, 4, Township 22 North, Range 7 East in the vicinity of the Taylor mine the strata have been folded into a well defined syncline trending North 45° West and approximately parallel to the other two anticlines just mentioned and lying to the southwest of them. The maximum width of this

syncline is a little over one mile and it may be traced northwesterly into the northwest quarter of Section 33, Township 23 North, Range 7 East. No pre-glacial outcrops have been found between this syncline and those exposures occurring in Section 26, Township 23 North, Range 7 East, just south of Kerriston.

The strata at Kerriston have a southwest dip in common with those on the northeast flank of the syncline at Taylor. It is possible that the strata at Taylor are the basal portion of those occurring on the east side of the Taylor syncline. There is also a possibility that there may be an anticline trending northwest to southeast somewhere between Taylor and Kerriston along the divide between Rock Creek and the head of Raging River. There is no direct evidence to support either view.

About three-quarters of a mile southwest of the Taylor syncline another anticline has been developed which trends North 45° West through the centers of Sections 4 and 10, Township 22 North, Range 7 East, into Sections 32 and 31 of the township immediately north. The position of this anticline has been largely determined from strikes and dips occurring at isolated points along its course.

In the discussion of the Newcastle-Issaquah anticline reference has been made to sedimentary outcrops containing coal seams, lying along Guy Creek in Sections 12 and 13, Township 23 North, Range 6 East. They may represent a block of Eocene sediments formerly resting upon the underlying basalts and which were dropped into their present position as a fault block between Tiger and Issaquah mountains. Observations taken on the strike and dip in Section 12, on Guy Creek, show an average strike of North 16° East and a dip of 45° to the northwest. Just south, in Section 13, the strike of these same strata appears to swing around to the northwest and assume a position almost due east and west. The dip is southwesterly and some minor faulting is indicated in places. In Section 12 these strata rest unconformably upon igneous rocks. The contact is not an intrusive one but rather one of sedimentation.

About one and one-half miles southwest of Preston a number of small local outcrops of shale containing carbonaceous seams project through the glacial drift. They are badly broken and dislocated and no definite structure could be determined. The prevailing strike is North 50 West and the dip very steep to the northeast.

QUIMPER PENINSULA AREA.

GEOGRAPHIC DISTRIBUTION.

The Quimper Peninsula forms the extreme northeastern corner of the Olympic Peninsula. The surface distribution of the Eocene deposits within this area is confined to two belts. One of these belts trends northwesterly from Hood Head and Olele Point to the south end of Discovery Bay and thence to Sequim Bay. The other belt lies to the southwest of Quilcene and extends along the western margin of Hood Canal to Mason County. Between these two belts and on the north side of the first belt, there are deposits of shale and sandstone of Oligocene age. Both the Eocene and Oligocene rocks are thickly covered with glacial drift. Such outcrops as occur are mostly along the shores of the Canal and its inlets.

The Eocene rocks in this region consist largely of basic andesites and intercalated bands of tuff, a part of which have been deposited in water. Exposures of these rocks occur along the shore line most of the distance from Olele Point to Hood Head. The contact between the Eocene and the overlying Oligocene sedimentaries appears in a low cliff immediately north of Olele Point. Shales rest directly upon basaltic andesites. No basal conglomerate is present at this locality and it is possible that the contact may be a fault plane rather than one of deposition. The rocks at Olele Point are distinctly tuffaceous and noticeably stratified. One-half mile south of the Point there is a long narrow channel extending inland a distance of about one mile to the small Indian village of Mats Mats and along the shores of this inlet the rocks may be studied in detail. To the south of this locality and towards Hood Head, the igneous

materials become more dense and occur as lava flows. Hood Head is a rock outlier of andesite and the country to the west of it is composed of glacial drift. The contact as mapped between Olele Point and Port Discovery Bay is only approximate since exposures of bedrock occur at only a very few localities. Andesite may be seen in contact with the overlying Oligocene conglomerates in a small creek near Anderson's Lake in Section 10, Township 29 North, Range 1 West. At this point the outcrops are at the falls and along the gorge of the creek just mentioned. Exposures of Eocene andesite occur in cliffs nearly 100 feet high along the east shore of Port Discovery Bay, between its head and Woodman Station. One-third mile north of Woodman Station Oligocene sandstones outcrop at the water's edge and dip at a very low angle to the north. Two miles south of Woodman Station conglomerates rest upon the igneous rocks. The contact on the north side of this belt of andesite may be traced from the western shore of Port Discovery Bay westerly to Sequim Bay. From the south end of Port Discovery Bay to the head of Dabop Bay at Quilcene the only bed rock exposures are shales and sandstones of Oligocene age. A high hill lies to the southwest of Quilcene, the central portion of which is composed of basic andesite. High upon its slopes it is thickly mantled with glacial gravels and sands. Similar igneous rocks form the hills bordering Hood Canal from Quilcene southward to Dosewallips River. These andesites, although disconnected by surface deposits of drift and the waters of Hood Canal, are in reality an extension of those in central Kitsap County. The contact between the igneous rocks and the Oligocene sedimentaries in the vicinity of Quilcene is very indefinite. Exposures of shale occur in the railway cuts two miles north of the town and exposures of andesite three miles to the southwest.

LITHOLOGY.

The textural and mineralogical characters of the rock vary considerably in different localities. On the east shore of Port Discovery Bay, south of Woodman Station, the formation is in

part a flow breccia. Large sized blocks of vesicular rounded masses of andesite occur embedded in a fine grained matrix of hardened tuff and lava exhibiting flow structure. Intercalated with this phase there are tongues of typical andesitic lava flows. A microscopic examination of the plagioclase crystals shows them to belong to the basic labradorite variety. Augite and minor amounts of hornblende compose the dark minerals. A few sections revealed the presence of a small amount of olivine. The surface exposures of the rock are deeply weathered and fresh specimens are difficult to obtain.

The tuffaceous phases are banded and often have thin layers of shale and clay interbedded. In the vicinity of Olele Point bands of tuff averaging two or three feet in thickness are interbedded with lava flows of about the same thickness. They are stratified and occasionally contain marine Eocene fossils.

GEOLOGIC STRUCTURE.

The main structural features involving the pre-glacial formations of the Quimper Peninsula consist of an anticline and syncline parallel to each other and trending southeast to northwest. The axis of the anticline lies along the area designated upon Plate IV as Tejon lavas. The banded phases of the lavas near Olele Point have a prevailing strike of east and west and a dip of 40° to the north. The overlying Oligocene sendimentaries exposed along the shores of Oak, Scow, Port Townsend and Port Discovery bays have an average east to west strike with a northerly dip ranging from 15° to 45°. An examination of the strikes and dips as platted upon the maps around the shores of Port Townsend and Scow bays indicates minor transverse folding of the strata on the north limb of the anticline.

Between Port Discovery Bay and Quilcene, Eocene rocks do not outcrop at the surface. There are a few exposures of the overlying Oligocene sandstones and shales. These have been folded so as to form a synclinal trough which also presumably involves the underlying lavas. Observations on strike and dip at the south end of Port Discovery Bay indicate that the nose

Eocene Basalts Exposed on the West Side of Cape Disappointment North of Entrance to Columbia River.

of the synclinal trough is not far to the southwest. It presumably extends easterly into Kitsap County but this cannot be proved on account of the lack of surface exposures. The anticline referred to may extend westerly past the south end of Sequim Bay.

PORT CRESCENT AREA.

GEOGRAPHIC DISTRIBUTION.

The type occurrence of the Eocene in this area is along the cliffs in the vicinity of Crescent Bay and Observatory Point on the south side of the Strait of Juan de Fuca. The region for some distance south of the shore is heavily covered with deposits of glacial drift but judging from such outcrops of Eocene rocks as are available they probably occupy the entire area southward from the shore line to the east-west center line of Township 30, Ranges 7 and 8 West. The western limit of these outcrops has been designated upon the geological map as extending from Section 16, Township 30 North, Range 8 West in a northwesterly direction to a point on the shore line on the Strait about two miles west of Port Crescent. This contact has been approximately drawn. To the south, the Eocene rocks extend into the northern ridges of the Olympic Mountains. To the east they may be seen outcropping in the canyon of Elwha River and presumably they underlie the glacial drift still farther east as far as Dungeness River.

The outcrops are conspicuous as bold rugged sea-cliffs ranging from ten to over one hundred feet in elevation and extending along the Strait from a point two miles west of Port Crescent to a point one mile east of Observatory Point in Freshwater Bay. Plate XIII.

Immediately south from the shore line, the entire region is so thickly covered with drift that all of the bed rock formations are deeply buried. The first reappear in the cuts along the county road in Section 16, Township 30 North, Range 8 West on the north side of Lake Sutherland. Immediately west of this point strata composed of sandstones and shales outcrop which overlie the Eocene and are believed to be of Oligocene age. To

the south of the valley formed by Lake Sutherland and Lake Crescent the Eocene rocks extend into the foothills of the Olympics. About six miles east of Lake Sutherland they are well exposed in the canyon of Elwha River. From that point eastward careful examination has not been made to determine their extent. About four miles south from Port Angeles they may be seen in Frazier Creek where they rest beneath the Oligocene sandstones and shales.

LITHOLOGY.

The rocks entering into the Eocene formations in the Port Crescent area are composed for the most part of basic igneous lavas of a basaltic character. Sandstones and shales are occasionally interbedded. The basaltic rocks vary in character, ranging from dark, fine-grained, dense lavas to vesicular and fragmental material. In many places the vesicular cavities are filled with secondary radiating crystals of natrolite which often attain a size of two inches in diameter. In a number of instances the flow lines are well exhibited in the cliffs along the shore. Often these are abruptly cut by small intrusive bodies of basalt which have forced their way up from below through the already consolidated surface flows giving the rock a much contorted appearance.

The interbedded sedimentary materials and water-worn tuffaceous materials vary considerably. The tuffaceous materials are sometimes distinctly bedded and show evidences of marine deposition. Interbedded with these there are often small lenticular bands of sandstone and shale. Sometimes the tuffs consist of a consolidated mass of heterogeneous materials ranging in size from that of a pea up to irregular sized blocks several feet in diameter. Many of the sandstones, shales, and stratified tuffaceous layers contain marine molluscan remains. These are quite numerous along the shore cliffs about one-half mile east of Tongue Point.

STRATIGRAPHY.

The contact between the Eocene formation and the overlying Oligocene sedimentaries occurs on the south shore of the

Strait of Juan de Fuca near the mouth of Whiskey Creek. From the mouth of this creek, Eocene rocks are exposed almost continuously easterly to Freshwater Bay. The upper portion of the Eocene section as exposed between the contact at Whiskey Creek and a point two miles east of Port Crescent consists of alternating marine sediments together with basaltic tuffs and flows all of which dip to the southwest. These rest upon basaltic flows of an unknown thickness. That portion of the Eocene formation in this region which can be measured is approximately 4,000 feet thick. The top of the section occurs at Whiskey Creek and the base is situated two miles east of Port Crescent.

Top of Section	*Feet*
Chiefly shale	380
Sandstone and small amounts of interbedded shale	200
Black fine grained tuff	130
Coarse grained massive sandstone and conglomerate	210
Massive agglomerate	280
Dark shale and thinly bedded sandstone	200
Basalt	410
Sandstone	700
Basalt	800
Basalt of unknown thickness	780
Base of Section	
Total	4090

FAUNA.

In the tuffaceous shales just east of Crescent Bay and in the sandstone layers interbedded with the tuffs at the east end of the bay are marine Tejon fossils. The following fauna has been collected:

Anomia subcostata Conrad
Cardium breweri Gabb
Modiolus ornatus Gabb
Venericardia planicosta Gabb
Calyptraea excentrica Gabb
Turritella uvasana Conrad.

The same fauna occurs in a similar tuffaceous material on the southeast coast of Vancouver Island at Albert Head. The fauna is typically Tejon and of the same age as faunas in Lewis and Cowlitz counties.

GEOLOGIC STRUCTURE.

The structure of this area may be regarded as consisting of the northeast limb of a northwesterly pitching syncline. To the west of Port Crescent for a distance of twelve miles a traverse was run along the beach and careful observations made on the strike and dip at various points. These were tied in to the traverse line. The axis of this syncline intersects the shore line near Twin Post Office. Along the road from Port Crescent to Lake Crescent at a point about two miles north of Fairview Post Office outcrops of sandstones and shales are well defined. Observations made on the strike and dip in this vicinity indicate the presence of the southeastern extension of this same synclinal axis. Near the center of the north side of Lake Sutherland the Eocene basalts appear, apparently resting uncomformably below Oligocene sediments. This point is assumed to be approximately the keel of the synclinal axis. The outcrop of the basaltic rocks cannot be traced on the surface northward to the coast line. The same contact, however, does occur on the coast-line about two miles west of Port Crescent and the overlying Oligocene sediments possess a northwest strike and southwest dip. The interbedded Eocene sandstones and shales have an average strike of North 70° West and an average dip of 30° to the southwest toward the axis of the syncline. This condition holds true as far east as Freshwater Bay. At one or two places in Crescent Bay, as may be seen upon the map, there are exceptions, but these may be explained as due to local faulting and slipping.

A synclinal trough trends southeasterly from Freshwater Bay and crosses Frazier or Tumwater Creek about three miles south of Port Angeles. The axis of this syncline crosses Morse Creek in Section 29, Township 30 North, Range 5 West.

In this portion of Washington during the Eocene eruptions of igneous materials were taking place almost continuously. The region around Crescent Bay was an embayment of the Eocene sea and basaltic lava flows were poured out on to the sea floor. At intervals ashes were ejected and these were afterwards worked over by the waves and redeposited as tuffaceous shales.

Similar conditions appear to have taken place as far north as Vancouver Island.

BALD HILLS AREA.

GEOGRAPHIC DISTRIBUTION.

The Bald Hills constitute a prominent topographic feature of central Kitsap County. When viewed from a distance they stand in marked contrast to the prevailing level bench topography so common to the greater portion of the Puget Sound Basin. These hills are composed of basic andesitic lavas together with small amounts of shale and sandstone all of which are of Eocene age. Outcrops of the formation are best exposed in the west central portion of the county to the south and west of Bremerton in Townships 23 and 24 North, Ranges 1 and 2 West. Accessible exposures may be seen along the shores of Sinclair Inlet immediately southwest of Bremerton.

If the glacial drift which covers the greater portion of the county were removed presumably the surface exposures of the entire southern half of the county would be composed of Eocene andesites and sediments. The lavas of the Bald Hills would directly connect with the same rocks of the Black Hills of Thurston and Mason counties as well as those of eastern Jefferson County.

CHARACTER OF OUTCROPS.

The surface exposures of the northern half of Kitsap County are entirely of glacial origin. The average elevation of the surface of this portion of the county is 500 feet above sea level. The monadnock-like ridges forming the Bald Hills have an elevation of 1,000 feet. They form the drainage divide between Hood Canal on the west and Admiralty Inlet on the east. Surrounding the Hills on all sides are very thick deposits of glacial drift. They are much thicker on the west than on the east. The Eocene formations pass beneath the drift and presumably form a part of the floor of Hood Canal and connect with the lavas near the mouth of Dosewallips River. Because of the heavy overburden of glacial deposits along the western slopes of the Bald Hills no surface outcrops of the Eocene formations occur along the eastern shore of Hood Canal in Kitsap County.

Bald Mountain ridge possesses a general trend of North 45° East, approximately parallel to Hood Canal. No exposures of basalt occur north of Bremerton. In Dyes Inlet which extends east from Bremerton to Silverdale, outcrops of the overlying Oligocene strata may be seen outcropping in the cliffs along the water's edge. To the north of this inlet no strata older than the Pleistocene glacial deposits are known to exist either in the cliffs along the shore line or inland.

On the eastern side of Bald Mountain ridge outcrops of basalt may be seen in places even as far as Sinclair's Inlet where the glacial drift has been removed by erosion. On the shores of this inlet, about two miles southwest of Bremerton in Sections 28 and 33, Township 24 North, Range 1 East, excellent exposures of the basalt may be seen. It outcrops along the shore for a distance of over one mile. At the north end of the exposure, it appears only a few feet above sea level and is overlain with glacial gravels and sand. The contact surface between the basalt and the glacial deposits exhibits fine examples of glacial grooving and scouring. Further to the southwest along the shore and near the head of the inlet a large quarry has been opened in the basaltic cliff. Here flow structure and the vesicular character of the basalt may be studied.

Southeast of Sinclair Inlet no outcrops of basalt have been noted at any point within Kitsap County. The only rocks observed are the various phases of glacial drift. To the southwest of Bremerton, towards Clifton and from there on to Dewatto the only exposures observed are of glacial origin. Basaltic lavas undoubtedly exist in this region below sea level but are so deeply buried with glacial deposits that no exposures outcrop at the surface.

LITHOLOGY.

Nearly all of the Eocene formations occurring within the Bald Hills area are composed of basaltic and andesitic lavas. Interbedded with these in a few places are narrow bands of sandstone. The prevailing lithologic character of the rock is of the typical black, fine but even-grained basalt. Associated

with this are numerous layers having a vesicular structure. The steam holes range in size from the head of a pin to over one inch in diameter. Commonly these are filled with secondary minerals such as natrolite. In a number of places and especially in Section 30, Township 24 North, Range 1 East, these amygdaloids of natrolite are very conspicuous. They are commonly referred to by the people living in that vicinity as fossil shells. In the exposures along Sinclair Inlet, southwest of Bremerton, both the fine-grained dense variety as well as the vesicular may be seen in the cliff. In those localities near the quarry where the fresher rock is continuously being exposed, these types may be studied to advantage. Here much jointing and fracturing has occurred and along these joint and fracture planes, secondary alteration is in evidence. The faces of the joint planes are commonly covered with a coating of red iron oxide. In the Bald Mountain ridge jointing is very prominent, giving rise to columnar structure. These columns are roughly hexagonal in shape and stand nearly vertical being at right angles to the lava flows. Interbedded with the basalts are occasional bands of fragmental material composed of rough angular blocks of basalt imbedded in finer tuffaceous materials. These are not, however, characteristic of the Eocene igneous materials of Kitsap County. Such sedimentary rocks as occur interbedded with the Eocene lavas are not very prominent. They have been observed only in a very few places. On the north side of Bald Hill ridge about three miles southwest of Chico in Section 12, Township 24 North, Range 1 West, sandstones may be seen in a small creek.

At this point they are cut by diabase dikes which were probably the feeders for some of the basaltic layers lying above this particular sandstone stratum. No fossils were seen in this sandstone but in so much as it is interbedded with the basaltic layers and since eruptions of basaltic lavas seem to have ended at the close of the Eocene, the sandstone may be also considered as belonging to this period.

GEOLOGIC STRUCTURE.

No very important details concerning the structure of the Eocene formations in Kitsap County can be determined. In the southern part of the county the lava flows appear to lie nearly horizontal or perhaps in gentle undulations. Extending in a direction a few degrees north of west from the entrance to Bremerton Inlet westward to Chico, there is evidence of a well-defined monocline or possibly the north limb of an anticline. This evidence is obtained from observations taken on the strike and dip of the Oligocene sandstones and shales at Restoration Point, Orchard Point and along the shores of Dyes Inlet. At least 9,000 feet of Oligocene strata are exposed and assume a persistent average strike of North 85° West with a dip ranging from 45° to 88° to the northeast. The basal beds which stratigraphically lie nearest to the Eocene basalts and which presumably rest unconformably upon the basalts are dipping nearly vertical. The actual contact between the overlying Miocene sediments and the underlying Eocene basalts is everywhere covered over with glacial drift. It seems probable that just south of this contact the basaltic layers have been folded downwards in accordance with the overlying Oligocene formations. It is possible, although there is no direct evidence to support such a view, that a nearly vertical fault plane may exist parallel with the contact. Between Quilcene and Discovery Bay in the eastern part of Jefferson County a syncline has been referred to which extends southeasterly in a general direction of South 45° East. The central part of this syncline is composed of Oligocene sandstones and shales. On the northeast and southwest flanks and lying beneath the sediments are Eocene basalts. The south limb appears to be a continuation of the Bald Hill basalts although its areal continuity is interrupted by the glacial deposits along Hood Canal. The basalts on the north side of this syncline outcrop at Hood Head and near Port Ludlow. If these outcrops were extended southeasterly they would diagonally cross the north end of Kitsap County from Port Gamble to Kingston. Because of the very thick covering of

glacial drift in this region, however, no pre-glacial rocks have been seen. It is to be presumed that they do underlie this portion of the county, though perhaps below sea-level, and if so, represent the reappearance on the north limb of the syncline of the same basaltic layers outcropping in the Bald Hills and forming the south limb of the syncline. The axis of such a syncline would extend through Township 26 North, Range 1 East, southeasterly through the north part of Bainbridge Island and thence across Puget Sound into the north part of Seattle.

BLACK HILLS AREA.

GEOGRAPHIC DISTRIBUTION.

The Black Hills are situated in the northwestern portion of Thurston County and extend into the extreme eastern part of Grays Harbor County. They involve a large part of Townships 16, 17, and 18, Ranges 3 and 4 West. They form a group of hills attaining an elevation of over 1,500 feet. They are composed almost entirely of basaltic lavas which are flanked on all sides by deposits of glacial drift.

To the north of the Black Hills, in Mason County, the surface formations are largely of glacial origin, but here and there projecting through the drift are rounded knobs of basalt exhibiting glacial scouring. It seems best to include these with the Black Hills for discussion. The north limits would then extend as far as Hoodsport on Hood Canal. The western limits would extend from Hoodsport southwesterly to Matlock and thence to McCleary in Section 11, Township 18 North, Range 5 West. From McCleary the contact between the Eocene formation and the Oligocene can be fairly determined from exposures in the creeks. It extends to Section 1, Township 17 North, Range 5 West, where it may be seen in the banks of Porter Creek. From Porter Creek it passes through Sections 12, 14, 23, 26, and 35 of the same township and range and thence due southeast to a point one mile west of Oakville where it may be seen in a Northern Pacific Railway cut. From Oakville the eastern limits of the basaltic area follow the line of

the railway past Gate to Little Rock. It then crosses the glacial outwash prairie of Thurston County to a point north of Plumb Station on the Port Townsend and Southern Railway. The basalts occurring at Tumwater Falls south of Olympia are included within this area. The northeastern limits of the area cannot be definitely determined because of the heavy overburden of glacial drift.

CHARACTER OF OUTCROPS.

Within the Black Hills the basaltic masses outcrop as high rounded hills which form the divide between those streams flowing northeasterly to Puget Sound and those flowing southwesterly into Chehalis River and thence direct to the Ocean. This divide varies in elevation. Between Little Rock and Gate along Black River it rises abruptly from an elevation of about 200 feet to an elevation of 800 feet. It extends due north as a ridge between Bordeaux Creek and Cedar Creek into the corner where Townships 17 and 18, Ranges 3 and 4, meet. In these hills the small creeks head and flow outwards through steep canyons. Extending up Bordeaux Creek through the lumbering town of Bordeaux there is a logging railroad, along whose grade many rock cuts have been made. In these the contact between the overlying glacial drift and the surface of the basalt may be seen. These surfaces always show the effect of glacial scouring in the form of grooves and polishing. On the higher slopes of the hills west of Delphi Post Office the vegetation is very heavy, but sufficient exposures exist to indicate that they are composed exclusively of Eocene basalt. In the smaller valleys leading out from these hills the soil is always of a typical reddish color due to the oxidation of the iron bearing minerals in the basalt below.

Extending from Little Rock to Gate on the west side of the Northern Pacific railway the basaltic rock forms a very steep escarpment in contrast to the level glacial outwash prairies immediately to the southeast. From Gate this escarpment swings around and extends in a direction North 20° West ap-

proximately parallel to the Northern Pacific railway and is three or four miles to the northeast of it.

About fifteen miles northwest of Gate the general elevation of the Black Hills gradually becomes much lower and in the vicinity of Matlock they form a low divide between the Puget Sound basin and Grays Harbor. From Matlock the elevation of this divide gradually increases and soon merges into a high rugged spur of the Olympic Mountains, which passes up the south side of the south fork of Skokomish River. The elevation of the gap at Matlock is 400 feet. This broad gap lying between the Olympics and the Black Hills is thickly veneered with glacial drift, but at numerous points projecting through it are outcrops of basalt always more or less rounded and scoured. The more important outcrops are located between the railroad extending from Shelton to Cloquallam and the branch extending from Kamilchie to McCleary. These outcrops are never over five or six acres in extent. The surrounding soil is generally of a deep red color. Many of the pebbles in the glacial gravels surrounding them are composed of the same material. These knobs are often at an elevation of twenty-five feet above the surrounding glacial drift. Numerous outcrops of these basaltic areas may be seen along the old logging railway track and also along the county road extending from Shelton to McCleary.

If the glacial drift of the Black Hills and the area northward to Hoodsport were completely removed it is very probable that the basalt would continue northward and directly connect with that occurring from Hoodsport northward to Quilcene and also with that in the Bald Mountain area of Kitsap County.

In Tumwater Canyon just south of Olympia the Des Chutes River has cut its canyon down through the drift and into the basaltic rock. This basalt, while not areally connected with that in the Black Hills to the west, is a continuation of it, the intervening area being covered with glacial gravel and sands.

Occasionally basalt may be seen outcropping in the eastern part of Thurston County and in the valley of Nisqually

River, as well as along the divide between the head waters of the Des Chutes and Skookumchuck rivers. These eastern basaltic areas are probably in reality the eastward extension of those in the Black Hills. The two areas are separated by the glacial outwash prairies south of Olympia.

To the northeast of the Black Hills among the inlets at the head of Puget Sound no basaltic formations outcrop at the surface. The only surface formations are glacial drift. Eocene basaltic masses may underlie Hartstine Island, McNeil Island, Carr Inlet and Tacoma, but there is no means of obtaining information concerning their character or structure. No deep well borings are available to determine how far below sea-level the upper surface of the basalt exists.

LITHOLOGY.

The Eocene formations within the Black Hills area are for the most part composed of igneous material. Occasionally interbedded sandstones and shales containing carbonaceous seams occur. The igneous materials consist of dense fine grained black basalt together with basaltic tuffs and vesicular layers, many of which are filled with amygdules of secondary natrolite. In places basaltic material of diabasic structure may be seen in the form of dikes cutting through the basaltic layers illustrating the methods by which the molten lavas reached the surface. These amygdaloidal phases of the basalt outcrop just north of the county road at Delphi, about seven miles southwest of Olympia. In the Black Hills proper and in the hills surrounding Bordeaux the basalt is of the fine grained, black, dense variety, ringing when struck with a hammer and breaking with a conchoidal fracture. In the exposures between Little Rock and Gate along the Northern Pacific Railway the basalt is often coarse grained and vesicular. In places in the ridge between Bordeaux and Gate, pyroclastic materials are interbedded with basaltic flows. These, however, are not a very conspicuous feature among the basalts of the Black Hills area.

The basaltic rock in Tumwater canyon south of Olympia is of the typical variety, ranging from fine to medium grained.

In the northern part of the area, in the vicinity of New Kamilchie, Cloquallam and thence northward to Shelton, the small knobs of basalt which outcrop are nearly always very fine grained and dense in appearance, and usually much weathered and altered. Extending into the rock several inches from the joint plains are masses of soft red material, largely composed of iron oxide. The rock itself is usually, even in the fresher portions, more or less altered.

About 1,000 feet west of Gate City in one of the small creek canyons leading up into the Black Hills, are exposures of sandstone and shale, containing low-grade coal seams. The sandstones are coarse grained, and have a yellowish brown color. They commonly show cross bedding and are presumably of estuarine origin. The shales are thinly bedded, of a brown color not very hard. In places there are beds of slightly carbonaceous shales interbedded with the sandstones. In Section 26, Township 16 North, Range 4 West, a seam of impure coal outcrops in the banks of a small creek which at this point has carved its canyon down through the sandstone leaving the igneous rock on either side. The sedimentary rocks are distinctly interbedded with basalts.

GEOLOGIC STRUCTURE.

Because of the absence of interbedded sedimentary rocks or stratified tuffaceous materials it is very difficult to determine the structure over the larger part of the Black Hills area. In the northern part of this district the basaltic outcrops form only isolated knobs, the intervening country being heavily covered over with glacial drift, thus rendering it impossible to actually connect any suggested structure from one outcrop to another. At the locality just west of Gate City where observations on the strike and dip of interbedded sandstones have been taken, the basalts along with the sedimentaries appear to be folded into a northwest-southeast direction. It is possible that the Black Hills, which trend northwest to southeast, may represent an anticlinal fold or warp, or possibly a series of closely folded

anticlines and synclines. Although there is no conclusive evidence on this point, the former is the more probable.

Along the western contact of the basalt in the Black Hills area, sandstones and shales of Oligocene age are resting unconformably upon the former. The sediments have a strike approximately parallel to the contact. This is nearly north and south with a low dip to the west ranging from 9 to 11 degrees. These Oligocene sandstones and shales constitute the east limb of the syncline whose axis trends nearly parallel to Chehalis River between Oakville and Elma. The basalt lying along the western margin of the Black Hills must form a part of this eastern synclinal limb. To the northeast of Olympia such structural relations as may exist among the basaltic flows are entirely obscured by the very heavy overburden of glacial drift. The lava formations are below sea-level. To the southwest of the high ridge exposed between Little Rock and Gate the greater part of the country is involved in glacial outwash prairies. In places along railroad, stream, or wagon road cuts the older bed-rock Eocene formations are exposed. The Eocene formations here contain a larger amount of sedimentary material in which igneous flows are interbedded.

ELK CREEK AND CHEHALIS RIVER AREA

GEOGRAPHIC DISTRIBUTION.

This area is situated in the southwestern corner of Lewis County in Townships 13 and 14 North, Range 6 West. It embraces the drainage area of the south branch of Chehalis River and Elk Creek. The belt is traversed by the Willapa Harbor branch of the Northern Pacific Railway. The areal boundary lines of the formation have in certain places been definitely established. In many other localities because of insufficient outcrops the contact has been only approximately drawn. The bed-rock formations of the entire drainage area of Elk Creek are almost entirely composed of basaltic rock. Beginning at a point one mile west of Pluvius on the railway in Section 3, Township 12 North, Range 6 West, the contact between the Eocene and Oligocene swings about North 45° West and follows along the

high ridge which forms the divide between Elk Creek on the east and Mill Creek, Wilson Creek and the head waters of North River on the west. At the head of Martin Creek, one of the tributaries to North River, the contact swings northeasterly, crosses the Lewis-Chehalis County line in the southeast quarter of Section 7, Township 15 North, Range 5 West and appears in the railway cut of the Grays Harbor branch of the O.-W. R. R. & N. Co. in Section 5 of the same township and range. It passes thence into the Black Hills area already described. The south boundary of the area may be arbitrarily chosen as the Lewis-Cowlitz County line. The areal outcrops of this formation extend much farther south, but for purposes of description they will be considered in connection with the Columbia River area. The eastern contact of this belt is very indefinite. Along the south branch of Chehalis River and from Pe Ell southward, basaltic rock outcrops. These exposures are conspicuous in the high ridge immediately east of the river. On the eastern side of this ridge in the valley of the headwaters of the main branch of Chehalis River the bedrock formations disappear from view. The entire country is covered with very thick deposits of non-consolidated sands and clays. The last bed-rock outcrops to appear are basalts. In the intervening area between the valley of the main branch of Chehalis River from Ceres to Wildwood on the west and the main line of the Northern Pacific on the east, occasional outcrops of bed-rock formations may be seen in the small canyons. These outcrops are partly of Eocene sedimentary origin and partly of Oligocene and will be described in the Cowlitz River area. It seems best to construct the eastern areal contact of the Elk Creek-Chehalis area on the eastern side of the valley of the main Chehalis River from Wildwood northward to Boistfort and from thence to a point on the Willapa Harbor branch of the Northern Pacific two miles west of Adna. From Adna the contact extends northwesterly along the divide between Bunker Creek and Chehalis River. Sedimentary rocks probably of Eocene age outcrop on Bunker Creek and contain carbonaceous seams. From the head of Bunker Creek the con-

tact extends about North 10° West past the head waters of Lincoln and Independence creeks and on the north side of the latter in Section 26, Township 15 North, Range 5 West, swings northeasterly and appears in the railway cut of the Oregon-Washington Railway and Navigation Co., in Section 10, Township 15 North, Range 4 West. It then passes under the alluvium of Chehalis River Valley and connects with the basaltic area at Gate in the Black Hills area.

CHARACTER OF OUTCROPS.

That part of the area under consideration south of the Willapa Harbor branch of the Northern Pacific Railway is mountainous in character and very inaccessible. It is densely timbered and logging has not been attempted on any large scale. Along the south branch of the Chehalis River due south from Pe Ell rock outcrops are abundant. They are almost entirely composed of basalt. Occasional bands of sandy shale are interbedded. In Section 10, Township 11 North, Range 5 West, quartz veins occur in the basalt. These are said to carry low values in gold and have been mined on a very small scale.

Along the line of the Willapa Harbor branch of the Northern Pacific Railway in the canyons of Chehalis River, outcrops of basalt are very common. Along the divide in the vicinity of Pluvius, Rock Creek and McCormick, the river has cut its channel into bed-rock. The surface exposures, however, are more commonly composed of thick deposits of Pleistocene clays and sands. At various intervals from Pe Ell to Doty and from Doty to Meskill, basalt with occasional interbedded layers of sandstone and shale are very conspicuous.

A traverse line was run from Doty westerly to the head waters of Elk Creek. The surface rocks in this drainage basin are for the most part composed of gravels, sands, and clays. Through these, Elk Creek has carved its course and exposed along its bed outcrops of basalt. These are exposed in places along the creek for a distance of six miles west of Doty. From there westerly to the head of the smaller branches of the creek the boulders along its course are composed of basalt. On the

headwaters of North River in the north half of Township 14 North, and the southeast quarter of Township 15 North, Range 6 West, basaltic outcrops make their appearance.

DIVIDE BETWEEN COLUMBIA AND WILLAPA RIVERS AREA.

GEOGRAPHIC DISTRIBUTION.

The Eocene formations occurring within this area involve a belt approximately twelve miles in width and thirty miles in length. The belt extends diagonally from Willapa Harbor across Pacific County southeasterly to the point where Lewis, Cowlitz, Wahkiakum and Pacific counties meet. Its northeastern contact with the Oligocene sedimentaries crosses North River in Section 31, Township 16 North, Range 9 West. It continues southeasterly through a country where rock outcrops are very scarce and consequently the line as drawn upon the maps is only approximate. Between the towns of Raymond and South Bend its position is more definite. A quarry has been opened in the Eocene basalts one and one-half miles northeast of South Bend in Section 23, Township 14 North, Range 9 West, and one-half mile east of this locality Oligocene sandstones and shales form prominent outcrops. From South Bend the contact trends about South 40° East and crosses Trap Creek two miles south of Holcomb Station in Section 11, Township 12 North, Range 8 West. It continues more nearly east along the west-east center line of Township 12 North, Range 7 West and then turns north crossing the railway about one mile west of Pluvius Station.

The southwestern contact of this belt is near the north end of Shoalwater Bay. From this point it trends nearly South 40° East. It passes through Sections 26, 27 and 28, Township 11 North, Range 9 West, and nearly due east across the center of Township 11 North, Range 8 West, and finally enters Wahkiakum County. It can be observed on the left fork of Grays River and near the head of Fossil Creek.

In Section 11, Township 10 North, Range 7 West, a small tongue shaped spur trends southwesterly for a distance of five miles. This narrow band is about one and one-half miles in width. In the south part of Section 13, same township and

Eocene Basalts on East Side of Cape Disappointment as Viewed From Ilwaco.

range, the contact extends nearly due east through the center of the township just east, and crosses the head waters of the several branches of Skamokawa River. It crosses the left and right branches of Alockaman River in Sections 21 and 23, Township 10 North, Range 5 West, and extends into Cowlitz County.

CHARACTER OF OUTCROPS.

This broad belt of the Eocene formation, whose areal limits have just been defined, occupies the divide between the drainage flowing northerly to the Willapa River basin and that flowing southerly to the Nasel and Columbia River basins. This divide ranges in elevation from two hundred to fifteen hundred feet above sea-level. It is very heavily timbered and in places at the headwaters of the several creeks there are steep escarpments. Disintegration of the rock formations has produced a very thick covering of soil which, together with the accumulations of vegetable material, render rock exposures difficult to find. In addition to these deposits produced by weathering there are formations of clays and sandy clays, together with gravels somewhat bedded and very loosely consolidated. These vary in thickness, ranging from a few feet to over 100 feet. No fossils are found in these and they undoubtedly represent river deposits formerly laid down over this region when it possessed a much lower elevation than it has today.

As this divide gradually approaches Shoalwater Bay and Willapa Harbor the Eocene formations become thickly covered with Pliocene or Pleistocene sands, gravels and clays. Along the shore at Bay Center, the mouth of Nemah River, and at Bruceport, the young horizontally bedded sediments are well developed and only in a few places back from the shore do the bed-rock formations outcrop.

Exposures of Eocene basalt may be seen in the city of South Bend and just south of town on the trail to Nemah. One of these outcrops, within the city limits, is being quarried for road material. In the several street cuts of the city the nearly horizontal Pleistocene clays may be seen overlying the basalt.

From South Bend a wagon road extends almost due south for a distance of five miles and then continues as a trail on to Nemah River. For the first three or four miles south of the city limits, the country is comparatively flat and about two hundred feet above sea level. Numerous small creeks have cut their canyons into this flat surfaced country and where the trail passes along the walls of these small valleys exposures of bedrock may be seen. In every case these are of basalt. At the point where the trail crosses the north fork of Nemah River outcrops of sandy shale may be seen in its bed and along its banks. The material is massive in character and no strike and dip could be obtained. These are believed to be interbedded with the basalts. From Nemah postoffice a road extends up the middle fork of Nemah River for a distance of five miles. At several points along the river the same sandy shale outcrops. In the northwest corner of Section 30, Township 12 North, Range 9 West the road crosses from the south to the north side of the river. In the road cut about 500 feet south from the bridge, exposures of sandy shales and shaly sandstones are well developed. Observations on the strike and dip were taken at this point and yielded the following data: Strike North 20° West, dip 30° to the southwest. Thence the road continues on for some distance and then becomes a trail which has become grown over so as to be no longer usable. Observations were made on the character of the rock up to the head of the river and such exposures as could be seen were of sandy shale.

From South Bend a road extends southwesterly to the Palix River. The greater part of this distance is covered with late Pleistocene sands and shales. In several places, however, the bedrock, consisting of basalt, is exposed.

In the high ridge extending from Nemah Harbor southeasterly and lying between South Nemah and Nasel rivers there are exposures of basalt. These are usually heavily covered with sands and clays. The majority of the exposures occurring along the banks of Nasel River are of Oligocene age. On a small creek in Section 33, Township 11 North, Range 9

West, basaltic outcrops are well developed, and interbedded with these are sandstones. In Section 20, Township 11 North, Range 8 West, the contact between the basalts and overlying sandstones and shales crosses Nasel River. From this point northward the river flows through a gorge with steep rocky slopes. A second gorge is well developed from the junction of the north fork of Nasel River and the main stream. This continues easterly a little over one mile to the point where Alder Creek enters Nasel River. About 500 feet up Alder Creek north from its junction with the main Nasel River, volcanic tuffs, together with shales, are interbedded with volcanic lavas. They have been much disturbed by faulting and contain marine fossils. A traverse line was run to the head waters of Alder Creek over the main divide and thence down to Trap Creek. Along the Alder Creek portion of the traverse such exposures of bedrock as were seen were composed entirely of basalts. All the boulders and stream pebbles were of the same material. Along the main divide the bedrocks are heavily covered with sands and clays and a dense growth of forest. In places boulders and blocks of hard, massive, brown, coarse grained sandstone were occasionally seen. They seem to be portions of interbedded layers of sedimentary rocks between the basaltic flows.

On the north side of the divide in the valley of Trap Creek very few exposures of bedrock occur. The boulders in the streams are almost entirely composed of basalt. The hill slopes are thickly covered with residual soil in addition to the Pliestocene sands and clays. Small outcrops of basalt were seen on the north side of Trap Creek about three miles south of Willapa River. In Section 3, Township 12 North, Range 8 West, at a point where the main trail crosses Trap Creek, sandy shales outcrop in the bank of the river. They have a strike of North 20° East and dip 30° to the northwest. Further observations were taken on sandstones and shales in Sections 1 and 12, same township and range, and from their lithological character they were thought to be of Oligocene age and the basaltic contact has been drawn just south. The sandy shale mentioned as occur-

ring in Section 3 is probably a sedimentary layer interbedded within the basalts.

About one mile west of Holcomb basalts form prominent outcrops along the Northern Pacific Railway grade and continue over the Willapa-Chehalis divide to Pe Ell. West of the contact rock exposures are not well developed, but such as do occur are a part of the overlying Oligocene formation.

A traverse line was run from the Northern Pacific Railway at Raymond southward, up the south fork of Willapa River and detailed observations made on the various outcrops along the traverse. In the north half of Section 6, Township 13 North, Range 8 West, the basalt contact was found to cross the river, to extend southeasterly and again recross it in the west half of Section 8, the same township and range. On the northeast side of the contact marine fossiliferous sandstones and shales of Oligocene age were seen dipping at an angle of 35° to the northeast. Within the basaltic areas extending southwesterly from the contact, numerous bands of sandstones and shale occur interbedded with the basaltic layers. No fossils could be found within these. Stratigraphically downwards from the Eocene-Oligocene contact the interbedded sedimentaries become less numerous and much thinner, and ultimately entirely disappear. In every case the upper limit of the basalt has been chosen as the contact between the Eocene and Oligocene formations. The interbedded sandstones and shales are regarded as belonging to the Eocene. Future detailed studies may prove that a part of the basalt belongs to the Oligocene.

On the left fork of Grays River, Oligocene sandstone and shales were found to outcrop as far as the boundary line between Pacific and Wahkiakum counties. The basaltic contact occurs approximately on the line between Section 5, Township 10 North, Range 7 West, and Section 32, Township 11 North, Range 7 West. Near the contact, layers of basalt interbedded with sandstones and shales begin to outcrop. In places layers of tuffaceous material are interstratified. For a distance of one-half mile north of the contact the sediments are quite commonly interbed-

ed with the basalts. Beyond that point basalt predominates. About one-half mile north of the junction of the left fork of Grays River and the main branch, on the former, the contact may again be seen. South of this contact the lower Oligocene shales and sandstones are well developed in the river banks, dipping southerly away from the basalt. Just north of the contact sandstones are interbedded with the basaltic layers. At this point, on the east bank of the river, a small diabase dike cuts the sedimentary rocks. Along the upper branches of the left fork of Grays River tuffaceous layers are very conspicuously interbedded with the basaltic flows. On the main branch of Grays River in Section 20, Township 11 North, Range 6 West, about two miles north of Blaney Creek the tuffaceous and shaly layers outcrop very prominently. Marine fossils are very common in the shales. The shales are somewhat baked and never exceed over 100 feet in thickness. The creek flows through a very narrow valley and at a point near the junction of Blaney Creek flows through a gorge of basaltic rock. The headwaters of the several branches of Grays River lie entirely in basaltic areas. The fossiliferous shales above mentioned are lower Oligocene.

The contact between the basalts on the east and the overlying fossiliferous sandstones on the west occur in Section 11, Township 10 North, Range 7 West. The basaltic hills trend southwesterly and form the divide between Grays River on the north and the west fork of Skamokawa River on the south. This divide is about 500 feet in elevation and thickly covered with Pliocene sands and clays, although basalt outcrops in places.

On the main fork of Skamokawa River, basalts occur in the hillside throughout the north half of Township 10 North, Range 6 West. The creek valleys are commonly filled in with gravel and sand, but the basalts outcrop on the divides. The exact position of the contact could not be determined, but has been approximately drawn midway between the last outcrops of sedimentary rocks and the first outcrops of basalt.

On Wilson Creek, which enters the main branch of Skamokawa River in Section 29, Township 10 North, Range 6 West, exposures of sedimentary formations occur at various points up to the basalt contact which lies in Section 24, Township 10 North, Range 6 West. The sedimentary rocks consist of isolated exposures along the river banks until the river valley flattens out and no more outcrops are seen. From that point northward the boulders in the creek are composed entirely of basalt and such exposures in the hills as are not covered with Pliocene sands and clays are also composed of basaltic rock. The contact has been drawn at this point as may be seen upon the accompanying maps. To the east of Wilson Creek in Township 10 North, Range 5 West, outcrops of basalt are common. The contact between this formation and the marine Miocene rock to the south crosses the left fork of Alockaman River in the south half of Section 22, Township 10 North, Range 5 West. Near the contact in the basalt some mining development work has been done upon small quartz veins said to carry low values in gold. This contact crosses the right fork of the river about two miles due east. To the north on the headwaters of the Alockaman River and on the divide leading over the headwaters of the south branch of Chehalis River the rock formations are entirely of basalt. The divide has an elevation of over 1,500 feet and the several branches of both rivers flow through deep gorges cut into the basalt.

LITHOLOGY.

The Eocene formations along the divide between Willapa River and the Columbia are composed for the most part of basaltic lavas and tuffs. Interbedded with these are shales, sandy shales, shaly sandstones, and sandstones. The basaltic lavas appear in various phases, ranging from the fine-grained, dense black specimens to the highly vesicular types. Mixed with these are fragmental layers in which huge angular blocks range in size from a few inches to several feet in diameter. These are imbedded in the finer grained basalts and all show the effects of flow action. The sandstones are coarse-grained,

of a grayish brown color and fairly hard, but not widely distributed.

GEOLOGIC STRUCTURE.

The structure of the area under consideration is very complex. In its broad general features there is an anticline trending approximately North 40° West from Willapa Harbor, but in the vicinity of the headwaters of Grays River it turns and extends nearly due east along the divide between the headwaters of the Alockaman and the south branch of Chehalis River. Along Willapa River on the northeast side of the anticline the overlying Miocene rocks are dipping to the northeast at angles ranging from 7° to 35°. On the south side of the anticline on Salmon and Nasel, Gray and Alockaman rivers, the average angle is 30° to the southwest, but ranges from 3° to 60° in various places.

CATHLAMET-GERMANY CREEK AREA.

GEOGRAPHIC DISTRIBUTION.

The area involved in this district lies on the north side of Columbia River in the southeastern part of Wahkiakum County and southwestern Cowlitz County. It embraces the northwest corner of Township 8 North, Range 3 West, and the north halves of Townships 8 North, Ranges 4, 5, and 6 West, the west half of Township 9 North, Range 3 West, and the lower two-thirds of Townships 9 North, Ranges 4, 5, and 6 West. The south limits of the district are defined by Columbia River and the north limits by an east-west belt of marine Oligocene sedimentary rocks. The north contact between the Eocene basalts and the Oligocene sedimentaries begins about one mile north of Skamokawa. From this point it extends nearly due east for three miles and then turns southeasterly and crosses Alockaman River in the north half of Section 32, Township 9 North, Range 5 West. Here it swings around on the east side of Alockaman River, and in Section 10 swings back again to the west side of the river, and then recrosses in Section 2 of the same township and range. It crosses from Wahkiakum into Cowlitz

County and may be traced across the head waters of Abernathy and Germany creeks. In Section 18, Township 9 North, Range 3 West the overlying Oligocene sediments thin out and disappear and the basalts are areally connected with those in the Coal Creek and Arkansas Creek areas which lie to the east and northeast.

CHARACTER OF OUTCROPS.

Almost the entire area of this district is composed of basaltic rock. It is not always exposed at the surface, however, because of the extensive covering of Pleistocene sands and clays. The elevations range from a few feet to 1500 feet above sea level. The area is dissected by several streams heading to the north near the Cowlitz-Lewis County line and flowing southward into the Columbia. These streams have developed valleys varying from a few hundred feet to over two miles in width. In most instances, however, the valley floors are covered with alluvium. Here and there exposures of basalt may be seen in the stream banks.

Detailed traverses were run along Alockaman, Skamokawa, Cameron, Abernathy, Germany and Mosquito creeks and from observation taken along these traverse lines the areal geological data as shown on the maps accompanying this report, have been obtained.

From Oak Point a logging railway owned by the Oak Point Piling Company extends up Cameron Creek for a distance of seven miles from its mouth. For the first two miles outcrops of basalt are very numerous. The valley here is very narrow with steep slopes on either side composed of basaltic cliffs.

For the next three miles the basalt exposures are not so prominent but may be seen wherever any grading has been attempted along the railway track. The basalts in the hills back from the track are covered with clay. At a point five miles up the creek a basalt cliff, having an elevation of 50 feet, occurs on the east side of the track. At this point on the surface there is about two feet of yellowish clay followed by several inches of black bituminous material which is in turn covered with a sandy clay. From the results of examinations made to

the west, this appears to lie between two basaltic flows, the upper one of which in this particular place has been removed by erosion. The soil in the vicinity of the creek is of a reddish color and is clearly derived from the underlying basalts. The traverse was extended up the creek two miles further and no more outcrops of basalt were seen. Such exposures as occur in the banks of the creek or around upturned tree trunks show a light colored clay. From the general appearance of the soil, however, the underlying bedrock is undoubtedly basalt to the head waters of the creek.

From the mouth of Abernathy Creek the Wisconsin Logging and Lumber Company's railroad extends up the stream for a distance of nine miles to the forks of the creek in Section 6, Township 9 North, Range 4 West. At this point the main track leaves the creek and veers off in a northwesterly direction for a distance of three miles. Frequent exposures of basalt occur over the entire distance to the forks of the creek. In a number of places there are steep basaltic cliffs showing well developed columnar jointing. From the forks of the river northwesterly in Wahkiakum County no further exposures of basalt were seen. However, there are numerous cuts along the track in which clays appear. These are a bright reddish-yellow, white and cream color. At a point about two and a half miles west of the river in Section 1, Township 9 North, Range 5 West, this clay is underlain with a bed of yellow sand, massive in character and with no bedding plains. These may be a part of the interbedded Eocene sedimentary formations, or possibly of late Pliocene or Pleistocene origin. In many places these are directly overlain by basaltic flows.

At a point about one-half mile west of the forks of the creek already referred to the same characteristic clay occurs, included in which are angular fragments of light pinkish colored rock which when closely examined is found to be a distinctly altered vesicular basalt. In places these clays appear to be tuffaceous.

An examination was made of the upper branches of the creek to their headwaters. Only one outcrop of basaltic rock

was seen in place. However the pebbles and boulders in the creek are composed of fine-grained black basalt which occasionally is vesicular.

A detailed traverse was made along Germany Creek from the point where it empties into Columbia River at the town of Stella to its headwaters in the center of Township 10, Range 4 West. At a point about one-fourth mile northwest of Stella along the wagon road on the east side of the creek the basaltic rock is well exposed. Two distinct flows appear at this place. The upper is a hard dense black rock, the lower is soft, much decomposed and in places distinctly tuffaceous, often assuming a yellow to creamish color.

The county wagon road extends up Germany Creek for a distance of four miles. Examinations made along this road, except in the immediate vicinity of Columbia River, yielded very few outcrops of bed rock. Wherever exposures were seen, however, they were entirely composed of basalt. In those localities where bedrock was not observed the surface soils were very heavily iron-stained and the pebbles and fragments found in them were composed of very badly weathered basalt.

Farther north in Section 1, Township 9 North, Range 4 West, at a point where a small creek comes in from the west, a massive brown sandstone outcrops. No observations on strike and dip could be obtained here. Further examinations made up the creek near its headwaters, indicate the bed rock to be basaltic in character.

LITHOLOGY.

The Eocene formations in the area just described are almost entirely composed of basaltic and andesitic lavas. Such sedimentary rocks as occur with them consist of very narrow bands of shale or sandstone intercalated between the flows. These are commonly more or less carbonaceous. The basalt as seen along Columbia River present a series of horizontal layers resting one above the other. The contact surfaces between these layers are slightly undulating. These layers vary considerably in general appearance, some being light and others dark, some

having been extensively weathered and others appearing hard, dense and fresh. Some of these bands are distinctly tuffaceous, others are vesicular and still others show well-defined flow structure. In numerous places along the river cliffs there are seams of clay between the individual lava flows often over two feet in thickness and in these there are sometimes very thin seams of carbonaceous materials. These facts indicate that the different bands represent individual lava flows. The clays lying between the different flows indicate that a considerable length of time intervened between the outpouring of each successive flow sufficient to allow extensive weathering of the rock prior to the outpouring of the next lava sheet. The presence of carbonaceous material between these layers indicates the growth of vegetation during the quiescent periods.

GEOLOGIC STRUCTURE.

Very little detailed information is at hand concerning the structure of the Eocene formations within this area. Such data as have been collected suggest that the formations have not been greatly disturbed since their deposition. They lie nearly horizontal with very gentle undulations. These undulations are not sufficiently prominent to be regarded as minor synclines and anticlines. On the north side of the belt an east-west synclinal trough has been developed. In the center of it the Miocene sedimentary rocks are also folded. These latter lie to the north of the district and will be considered in the discussion of the Oligocene areas.

Because of the very thick veneer of Pleistocene sands, clays and gravels which overlie the bed rock Eocene formations, faulting is very difficult to detect. Minor fault plains ranging from a few inches to two or three feet are common, but are local in character. They have no prevailing direction.

ILWACO AREA.

GEOGRAPHIC DISTRIBUTION.

Eocene formations outcrop prominently in the high rugged rocky point at the north entrance to Columbia River. About three square miles of territory are involved.

The rocks outcropping in the point south of Ilwaco attain an elevation of 200 feet above sea level. The west side of this headland is directly exposed to the waves of the Pacific Ocean. Two points jut out into the ocean, namely North Head and McKenzie Head. Even at the lowest tides it is impossible to pass around these points but between them are coves with broad gravelly beaches and back of these beaches the elevations are comparatively low, forming shallow divides with the area on the eastern side of the cape. The eastern shore is more or less protected from the action of the ocean and in recent years shoaling has occurred to such an extent as to build up prominent sand spits. This high rocky cape ends abruptly immediately west of the town of Ilwaco and the country from that point northward is largely composed of low hills of Pleistocene gravels. Near the ocean a sandbar has been developed to the north for a distance of fifteen miles.

LITHOLOGY.

The rocks involved in Cape Disappointment are entirely of Eocene age and composed of varied types of lava flows, interbedded shales and sandstones, tuffaceous layers and fragmental material. The surface of the cliffs are covered with polygonal shaped blocks, due possibly to contraction at the time of cooling. A similar condition prevails on the north side of McKenzie Head. Along the eastern shore of Ilwaco Point about one-half mile south of the town of Ilwaco, shales and sandstones are interbedded with the lava. On their upper surfaces where they come in contact with other basaltic flows they are baked and slightly metamorphosed. In places, especially at a point one mile north of Fort Canby barracks, both the volcanic layers as well as the sandstones and shales are cut by diabase dikes. On the opposite side of Ilwaco Point north of McKenzie Head similar shales appear interbedded with basalt. Here they are badly baked, twisted and squeezed as on the eastern side. About one-half of the entire assemblage of volcanic materials occurring in this area is composed of tuffaceous and fragmental rocks.

These are firmly cemented and always show considerable alteration. (Plates XIV and XV.)

GEOLOGIC STRUCTURE.

Because of the crushing which the Eocene rocks in Ilwaco Point have undergone, the detailed structure is difficult to determine. Observations taken on strike and dip of the interbedded shales on the eastern side of the point show an average strike of nearly north and south with a dip ranging between thirty and fifty degrees to the east. Just east of this point and one-half mile east of Ilwaco prominent exposures of interbedded shales and sandstones outcrop on the beach. These have an average strike of North 30° East, and dip about 57° West. There are no volcanic materials in this locality and they are presumably younger than the Eocene. If so, there would appear to be a fault trending nearly north and south through the town of Ilwaco which has thrown the strata on the eastern side of Ilwaco Point downwards.

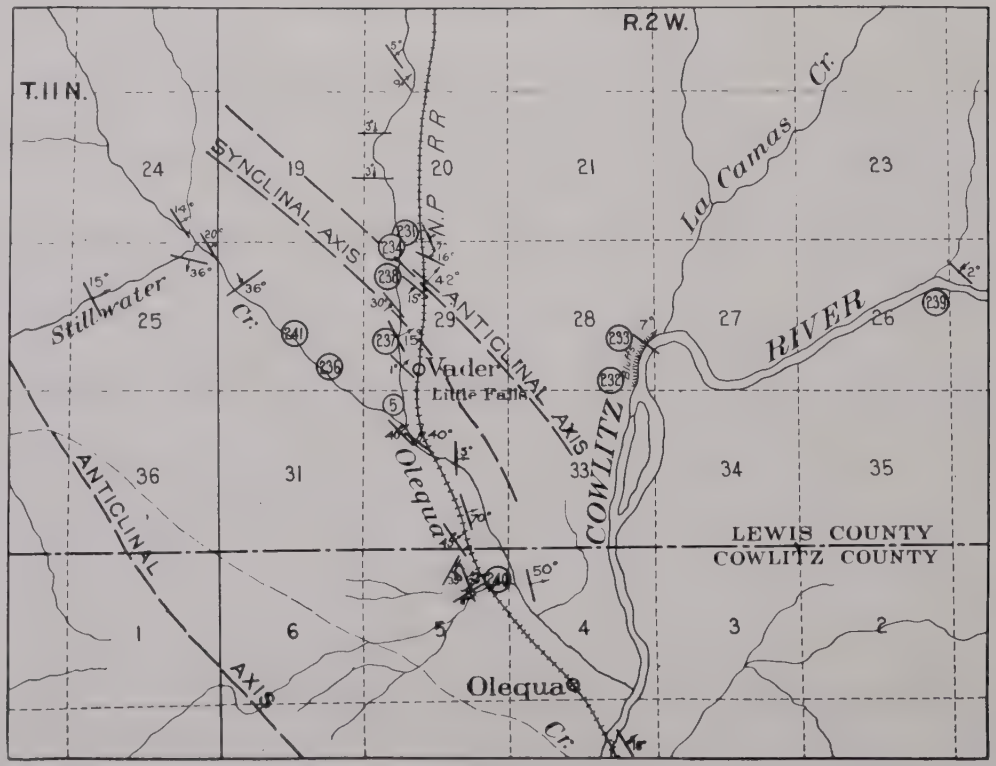
LOWER COWLITZ VALLEY AREA.

GEOGRAPHIC DISTRIBUTION.

The area involved in this particular district is situated in the Cowlitz River valley and extends from the town of Castle Rock northward to Winlock, a distance of about fifteen miles. The larger part of this distance is traversed by Cowlitz river which trends nearly north and south, but in Section 28, Township 11 North, Range 2 West, it turns abruptly and extends nearly due east toward the summit of the Cascades. At the town of Winlock, Olequah Creek occupies a wide valley, trending a little west of south to the town of Vader where it joins Stillwater Creek. Farther south the latter creek empties into Cowlitz River.

CHARACTER OF OUTCROPS.

Both sides of the valleys just mentioned are bordered by low wooded hills. The entire region has been more or less heavily covered with Pleistocene gravels and sands. These have in part been subsequently cut into and removed by the existing streams. Along the banks of Cowlitz River and also along those of Still-



Geological and Structural Map of the Region at the Junction of Olequa and Stillwater Creeks, Lewis County.

water and Olequah creeks there are occasional outcrops of Eocene formations. The Northern Pacific Railway grade from Castle Rock to Winlock lies very close to Cowlitz River and also to Olequah Creek. At a number of localities the railway cuts have exposed the Eocene strata. A traverse line has been extended along the railway track and also along both Stillwater and Olequah creeks. All of the Eocene exposures have been tied in so that their exact position has been located. Observations have been taken on strike and dip at every point possible and tied into the traverse line, as may be seen on Plate XVI.

Beginning at the town of Castle Rock and extending northward for a distance of two miles the only rock exposures are horizontally bedded gravels, clays and sands of Pleistocene age. Near the junction of Toutle and Cowlitz rivers basalts and sandy shales are found interbedded. The basalts occur distinctly as flows and exhibit well-defined columnar structure. Near the base of these flows the lava is somewhat tuffaceous and agglomeratic. From Toutle River northward for two miles the Eocene formations are not exposed. The first outcrops encountered, however, are interbedded basaltic flows and shales. Immediately south of the railway crossing of Cowlitz River an extensive basaltic flow appears having a strike of North 30° West and a dip of 10° to the northeast. After crossing Cowlitz River the Northern Pacific Railway grade extends along the west side of Stillwater Creek to the town of Vader. Exposures of Eocene rock are to be found in the railway cuts for a considerable part of this distance. The formation as here exposed consists of interbedded marine and brackish water sandstones and shales together with interbedded basalt flows. The prevailing strike of the formation in this vicinity is North 30° West with dips to the northeast ranging from 20° to 80°. This portion of the formation is stratigraphically higher than that just mentioned on the railway crossing on the Cowlitz and Toutle rivers. It lies stratigraphically below the Eocene ex-

posures extending up Stillwater Creek from its junction with Olequah Creek.

From the junction of Olequah and Stillwater creeks exposures of the Eocene formation extend almost continuously up the former creek to Winlock. No igneous rocks of any nature were found in this portion of the series. The prevailing type of rock is a shale or sandy shale, partly marine and partly of brackish water origin. The strata have a predominate northwesterly strike with a very low average dip to the northeast. In section 28, Township 11 North, Range 2 West at the big bend in Cowlitz River, steep cliffs of shale are exposed for a distance of one-half mile. These contain an extremely rich marine Tejon fauna represented by fossil localities Nos. 232 and 233. The strata at this locality have a strike of 45° to the west and dip at an angle of 8° to the northeast. The intervening area between this locality and Olequah Creek is entirely covered with Pleistocene gravels and sand. The same strata, however, appear to cross Olequah Creek in Section 8, Township 11 North, Range 2 West. At this point on Olequah Creek a similar, although not so complete, marine Eocene fauna occurs. At a point about one mile south of Winlock station in the banks of Olequah Creek shales are exposed, containing a marine invertebrate fauna somewhat different from the underlying Tejon. A number of Oligocene species occur, such as *Nucula dalli* n. sp., *Solen parallelus*, and *Macrocallista pittsburgensis* Dall. The strike of the strata at this point is North 20° West and the dip 4° to the northeast. Just north of Winlock station similar strata are exposed having a strike of North 75° West and a dip of 22° to the northeast. These shales contain a fauna having Miocene characteristics.

STRATIGRAPHY.

The lowest Eocene beds exposed in the area under discussion are to be found in the railroad cuts at the Toutle River railway crossing. The strata outcropping from this point northward to the Cowlitz river railway crossing are successively stratigraphically higher. The same condition holds true from

Olequah northward to Winlock. Altogether approximately eight thousand feet of strata are involved. The contact between the Eocene and Miocene is at a point about one and one-half miles south of Winlock. Whether the two formations are unconformable or not, could not be determined. The strike and dip of the two are approximately the same. It is possible that deposition went on continuously from Eocene to Miocene and that the non-fossiliferous shales intervening may be Oligocene.

GEOLOGIC STRUCTURE.

The predominant structure in the Cowlitz Valley region is that of a northeasterly pitching monocline. From Castle Rock northward to the railway crossing at Cowlitz River the prevailing strike is nearly east and west with a low dip ranging from 4° to 12° to the north. At a point several hundred feet south of the Cowlitz River railway crossing, the Eocene strata make a sharp turn and strike to the northwest in a direction approximately North 30° West, with a low dip to the northeast. At a point about 1,000 feet north of Vader there is a slight buckling of the strata in the flank of this northeasterly pitching monocline. The buckling is sufficient to form a very shallow anticline, trending North 40° West and crossing Olequah Creek about three-fourths of a mile north of Vader. The strata exposed at the axis of this buckle or anticline reappear at the surface on Olequah Creek near its junction with the Stillwater.

North of Winlock Eocene exposures are heavily covered with Pleistocene sands and gravels. Occasional outcrops of sandstone occur resting horizontal. They first reappear highly tilted and pitching to the south in the vicinity of Chehalis. It is probable that a broad synclinal trough trending northwest and southeast occupies the intervening area between Winlock and Chehalis and that the extreme lower portion of the Oligocene may lie in this depression.

CHAPTER 4.

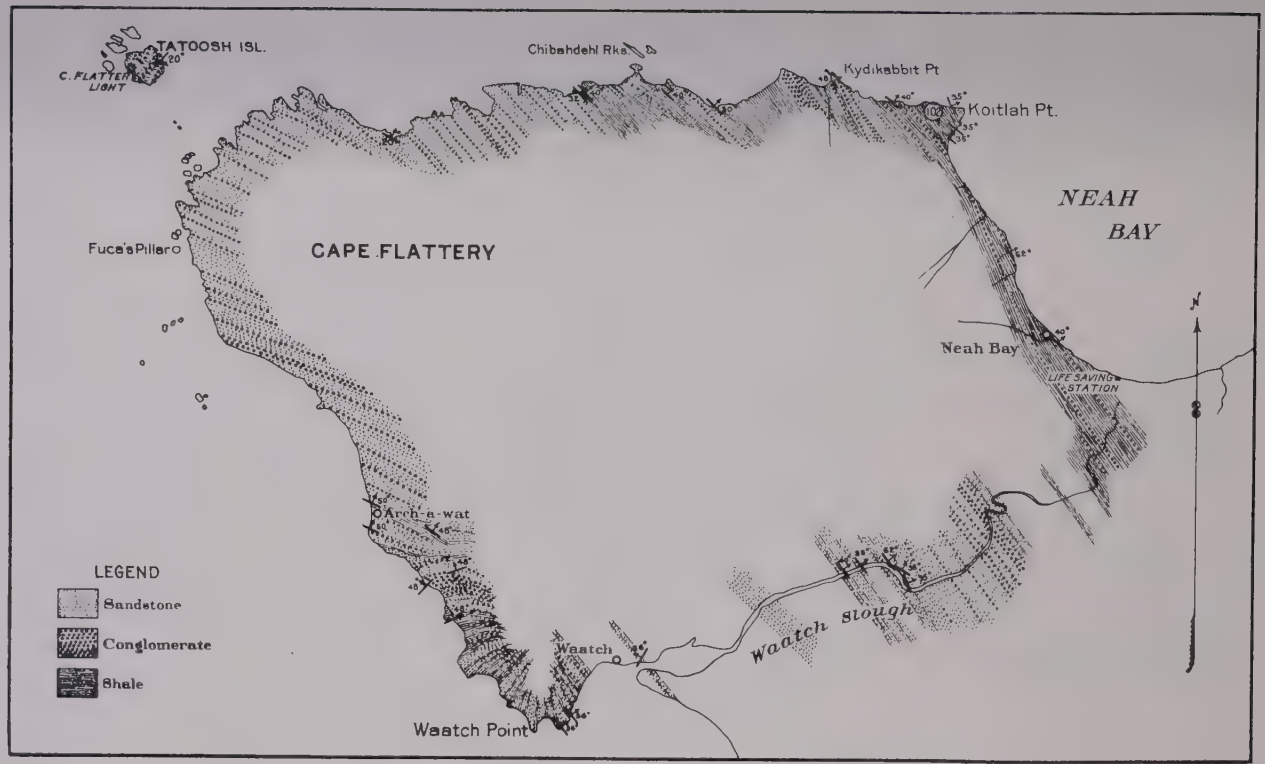
OLIGOCENE FORMATIONS.

GENERAL STATEMENT.

The use of the term Oligocene as applied to marine formations of the Pacific Coast is involved in controversy. Early investigators of west coast geology divided the Tertiary into the Eocene, Miocene and Pliocene periods. Later studies showed that a well defined and widely spread unconformity existed in the middle Miocene. Certain deposits which had formerly been regarded as Miocene were found to contain a fauna possessing Eocene as well as Miocene characteristics. Such deposits were finally regarded as being the same age as the Oligocene of Europe. At the present time there is no general agreement on the west coast as to where the line between the Oligocene and lower Miocene shall be drawn.

In the western portion of North America extensive lacustrine and land deposits were in existence during the Oligocene epoch. From these deposits a rich fossil mammalian fauna has been collected. Detailed studies have been made on the evolutionary development of these forms of life and as a result it is possible to recognize several divisions of the Oligocene. Unfortunately up to the present time it has not been possible to correlate the Oligocene land deposits of the Great Basin and Rocky Mountain regions with the deposits of marine origin in western California, Oregon and Washington.

During the past twenty years certain fossiliferous strata occurring at Astoria, Oregon, have been recognized as Oligocene. The shales and sandstones exposed along the south shores of the Strait of Juan de Fuca and at the entrance to the Bremerton Navy Yard have in part been referred to as Oligocene. Poorly preserved faunas have been found in shales in the Coast Ranges south of San Francisco and have been described as the San Lorenzo formation. This formation is regarded as Oligocene and the Oligocene strata of Washington and Oregon have in part been correlated with it.



Geological and Structural Map of Cape Flattery.

Oligocene deposits of western Washington are for the most part of marine origin. They have a total aggregate thickness of 15,000 feet and occur along the south side of the Strait of Juan de Fuca, in the Puget Sound Basin and in southwestern Washington. Marine faunas are abundant and constitute several faunal zones. The term Clallam formation is applied to these strata.

FAUNAL ZONES.

Three faunal zones are recognized in the Oligocene of western Washington. The strata containing each of these faunas are referred to as horizons. The faunal zones beginning with the oldest are the Molopophorous lincolnensis Zone, the Turritella porterensis Zone and the Acila gettysburgensis Zone. The corresponding sedimentary horizons identified by these zones are designated as the Lincoln, Porter and Blakeley. The faunas occurring in each of the above zones are distinct and many of the species do not range into the zones above or below. There does not seem to be sufficient evidence at the present time to warrant subdividing the Oligocene into three formations.

MOLOPOPHOROUS LINCOLNENSIS ZONE.

The type section in which this zone occurs is situated in southwestern Thurston and northwestern Lewis counties, and occupies an area of about 40 square miles. The distribution as indicated upon Plate III is only approximate. The contact lines have been drawn upon the basis of very poor field evidence. It is quite possible that certain shales occurring in Chehalis County on Porter Creek in Sections 11 and 14, Township 17 North, Range 5 West, may contain a fauna belonging to this zone. The sandy shales outcropping in the banks of Olequah Creek in Sections 28, 29, 30, 31, 32 and 33, Township 12 North, Range 2 West, near Winlock, are presumably a part of the Lincoln Horizon.* The surface outcrops are limited and are included on Plate III with the Tejon formation. The covered area in Kitsap County, between the Eocene basalts exposed at Charleston and the shales

*After the printing of the maps Oligocene fossils were discovered.

and conglomerates at Rich Passage, may also in part belong to this horizon.

The most characteristic species of this zone are: *Acila schumardi* Dall, *Cardium lorenzanum* (Arnold), *Crassatellites washingtonensis* Weaver, *Glycimeris chehalisensis* Weaver, *Pitaria dalli* Weaver, *Macrocallista pittsburgensis* Dall, *Dentalium substramineum* Conrad, *Calyptraea excentrica* (Gabb), *Exilia dickersoni* (Weaver), *Exilia lincolnensis* Weaver, *Hemifusus washingtonensis* Weaver, *Drillia hecoxi* (Arnold), *Natica lincolnensis* Weaver, *Molopophorous lincolnensis* Weaver, *Strepsidura washingtonensis* Weaver, and *Turris thurstonensis* Weaver.

The following species are common to the marine Tejon occurring at locality 1 on Cowlitz River east of Vader and the Molopophorous lincolnensis Zone: *Crassatellites washingtonensis* Weaver, *Leda gabbi* Conrad, *Solen parallelus* Gabb, *Dentalium substramineum* Gabb, *Calyptraca excentrica* (Gabb), *Exilia dickersoni* (Weaver), *Hemifusus washingtonensis* Weaver, and *Strepsidura oregonensis* Dall.

The following species are common to the Molopophorous lincolnensis Zone and the Turritella porterensis Zone: *Cardium lorenzanum* (Arnold), *Crenella porterensis* Weaver, *Dentalium substramineum* Gabb, *Drillia hecoxi* (Arnold), and *Natica washingtonensis* Weaver.

Such forms as *Marcia oregonensis* Conrad, *Phacoides acutilineatus* Conrad, *Thyasira bisecta* (Conrad), and *Thracia trapezoidea* Conrad are entirely absent from the Molopophorous lincolensis Zone, although they are among the most characteristic species in the Turritella porterensis Zone at Porter. The fauna as a whole is distinct from the Tejon fauna below and the Turritella porterensis Zone above.

TURRITELLA PORTERENSIS ZONE.

The type locality in which the deposits containing this fauna occur is located in Grays Harbor County, in Township 17 North, Range 5 West. Fossiliferous marine strata occur along the bluffs of Chehalis River both east and west of the town of

Porter as well as on Porter Creek. Similar deposits occur at different localities on Lankner Creek to the south of Chehalis River in Township 17 North, Range 6 West. The faunas of this zone are distinctly different from the underlying Molopophorous lincolnensis Zone as well as the Acila gettysburgensis Zone of the Puget Sound region. The most common species occurring in this zone are: *Cardium lorenzanum* (Arnold), *Crenella porterensis* Weaver, *Malletia chehalisensis* Arnold, *Marcia oregonensis* (Conrad), *Thracia trapezoidea* Conrad, *Thyasira bisecta* (Conrad), *Phacoides acutilineatus* (Conrad), *Drillia hecoxi* (Arnold), *Exilia lincolensis* Weaver, and *Turritella porterensis* Weaver.

Those forms which are common to the Molopophorous lincolnensis Zone and to this zone have already been mentioned. Many of the species occurring in this zone are very common to the Acila gettysburgensis Zone and it is possible that the extreme lower portion of the stratigraphic section exposed at the entrance to the Bremerton Navy Yard may be the equivalent of the upper beds at Porter. Such species as *Acila gettysburgensis* Reagan, *Macrocallista vespertina* (Conrad), *Modiolus directus* Dall, *Panope generosa* (Gould), *Eudolium petrosum* Conrad, *Turcicula washingtoniana* Dall, and *Turritella porterensis* Weaver which are very characteristic of the Acila gettysburgensis Zone are entirely absent from the Turritella porterensis Zone. The dark colored shales exposed three miles west of Port Crescent in Clallam County may belong to the Porter Horizon.

ACILA GETTYSBURGENSIS ZONE.

The type section of the Acila gettysburgensis Zone is to be found within the strata outcropping at the entrance to the Bremerton Navy Yard. Excellent exposures containing marine fossils occur at the south end of Bainbridge Island as well as on the opposite shore to the south. The deposits consist of interbedded massive conglomerates and medium grained sandy shales possessing a thickness of at least 9,000 feet. The lower-

most strata which are exposed outcrop at Orchard Point and the highest on the north shores of Blakeley Harbor. Detailed stratigraphic surveys show that the conglomerates at Orchard Point are below the sandstones and shales at Bean Point on Bainbridge Island and that the beds at Bean Point are about 2,000 feet below the fossiliferous strata at Restoration Point. The fauna occurring within the lower portion of the Bremerton Inlet section are identical with those at the well known locality just north of Restoration Point.

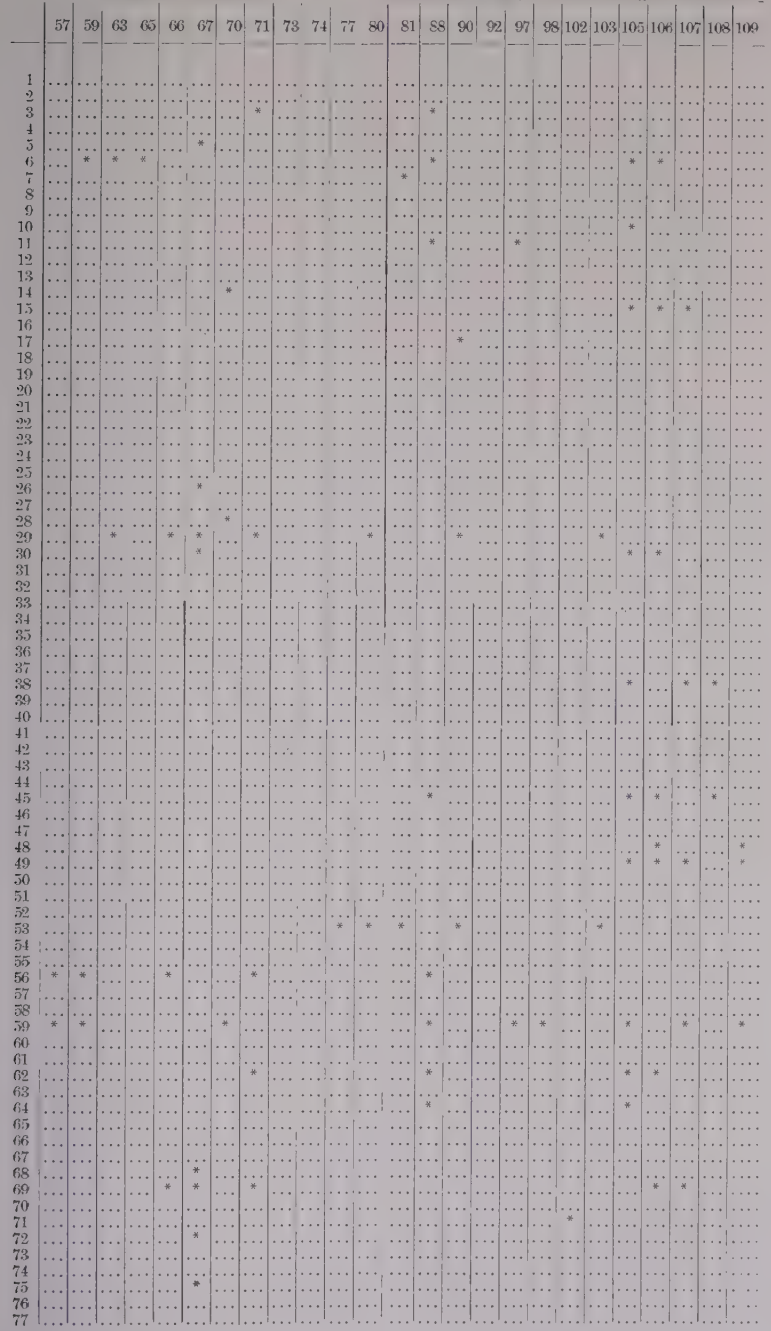
The Acila gettysburgensis Zone is represented within the city limits of Seattle, Newcastle Hills, Cathcart and along the Strait of Juan de Fuca from a point two miles west of Gettysburg westerly to a point halfway between Twin River and Pysht. The conglomerates and overlying shales exposed along the north portion of Cape Flattery and along the Strait of Juan de Fuca easterly to the mouth of Sekiu River also contain faunas belonging to this zone.

The species most common to this zone are: *Acila gettysburgensis* Reagan, *Macrocallista vespertina* (Conrad), *Marcia oregonensis* (Conrad), *Modiolus rectus* Dall, *Panope generosa* (Gould), *Phacoides acutilineatus* (Conrad), *Spisula albaria* (Conrad), *Solemya ventricosta* Conrad, *Tellina oregonensis* Conrad, *Thracia trapezoidea* Conrad, *Thyasira bisecta* (Conrad), *Crepidula praerupta* Conrad, *Eudolium petrosum* Conrad, *Miopleiona indurata* Conrad, *Turcicula washingtoniana* Dall, and *Turritella blakeleyensis* Weaver.

A list of the species known to occur in the Oligocene and lower Miocene of western Washington follows. This table also includes a list of species occurring at the more important localities. A reference list of the localities may be referred to on page 299.

	LIST OF SPECIES	9	10	12	13	24	25	29	43	44	45	53	54	56
	PELECYPODA													
1	Acila shumardi Dall	*							*					
2	Acila gettysburgensis Reagan	*												
3	Acila conradi Meek												*	*
4	Anomia subcostata Conrad													
5	Arca trilineata Conrad											*	*	
6	Arca montereyana Osmont											*	*	
7	Cardium lorenzanum (Arnold)		*											
8	Cardium coosensis Dall													
9	Cardium lincolnensis Weaver													
10	Cardium vaqueroensis Arnold													
11	Chione securis (Shumard)												*	
12	Chione clallamensis Reagan													
13	Chione olympidea Reagan													
14	Chione catheartensis Weaver			*	*									
15	Chione temblorensis Anderson													
16	Callocallista arnoldi Weaver													
17	Crenella porterensis Weaver				*									
18	Crassatellites washingtonensis Weaver													
19	Crassatellites cowlitzensis Weaver													
20	Crassatellites lincolnensis Weaver													
21	Crenella washingtonensis Weaver													
22	Glycimeris chehalisensis Weaver													
23	Leda washingtonensis Weaver													
24	Leda lincolnensis Weaver													
25	Leda chehalisensis Weaver													
26	Leda oschsneri Anderson													
27	Macrocallista pittsburgensis Dall													
28	Macrocallista vespertina Conrad			*	*									
29	Marcia oregonensis (Conrad)		*	*	*						*			
30	Macoma secta Conrad													
31	Macoma nasuta Conrad													
32	Macoma calcaria Gmelin		*											
33	Macoma clallamensis Reagan													
34	Macoma wynoocheensis Weaver													
35	Modiolus directus Dall		*											
36	Modiolus inflatus Dall													
37	Malletia chehalisensis Arnold								*					
38	Mytillus mathewsoni Gabb													
39	Mytillus sammamishensis Weaver													
40	Mytillus snohomishensis Weaver													
41	Nucula washingtonensis Weaver													
42	Ostraea veatchii Gabb													
43	Ostraea lincolnensis Weaver													
44	Ostraea idraensis Gabb													
45	Panope generosa (Gould)			*										
46	Pandora washingtonensis Weaver													
47	Pitaria dalli Weaver													
48	Pecten propatulus Conrad						*						*	
49	Pecten fucanus Arnold													
50	Pecten peckhami Gabb									*				
51	Pecten porterensis Weaver													
52	Pecten alockamanensis Weaver											*	*	
53	Phacoides actutilineatus (Conrad)		*	*	*	*	*	*					*	
54	Phacoides annulatus Reeves													
55	Solemya ventricostata Conrad			*				*						
56	Solen curtus Conrad								*					
57	Solen lincolnensis Weaver													
58	Solen parallelus Gabb													
59	Spisula albaria (Conrad)				*								*	*
60	Spisula catilliformis Conrad													
61	Tapes staleyi Gabb											*		
62	Tellina obruta Conrad												*	*
63	Tellina lincolnensis Weaver													
64	Tellina oregonensis Conrad													
65	Tellina arctata Conrad													
66	Tellina conjesta Conrad													
67	Tellina nuculana Dall	*		*										
68	Tellina nevadensis Anderson													
69	Thracia trapezoidea Conrad			*	*									
70	Thracia oregonensis Dall													
71	Thyasira bisecta (Conrad)		*	*			*							
72	Venericardia subtenta (Conrad)	*		*										
73	Venericardia chehalisensis Weaver									*				
74	Yoldia oregona Shumard													
75	Yoldia impressa Conrad	*	*	*										
76	Yoldia submontereyensis Arnold											*	*	
77	Yoldia sammamishensis Weaver													

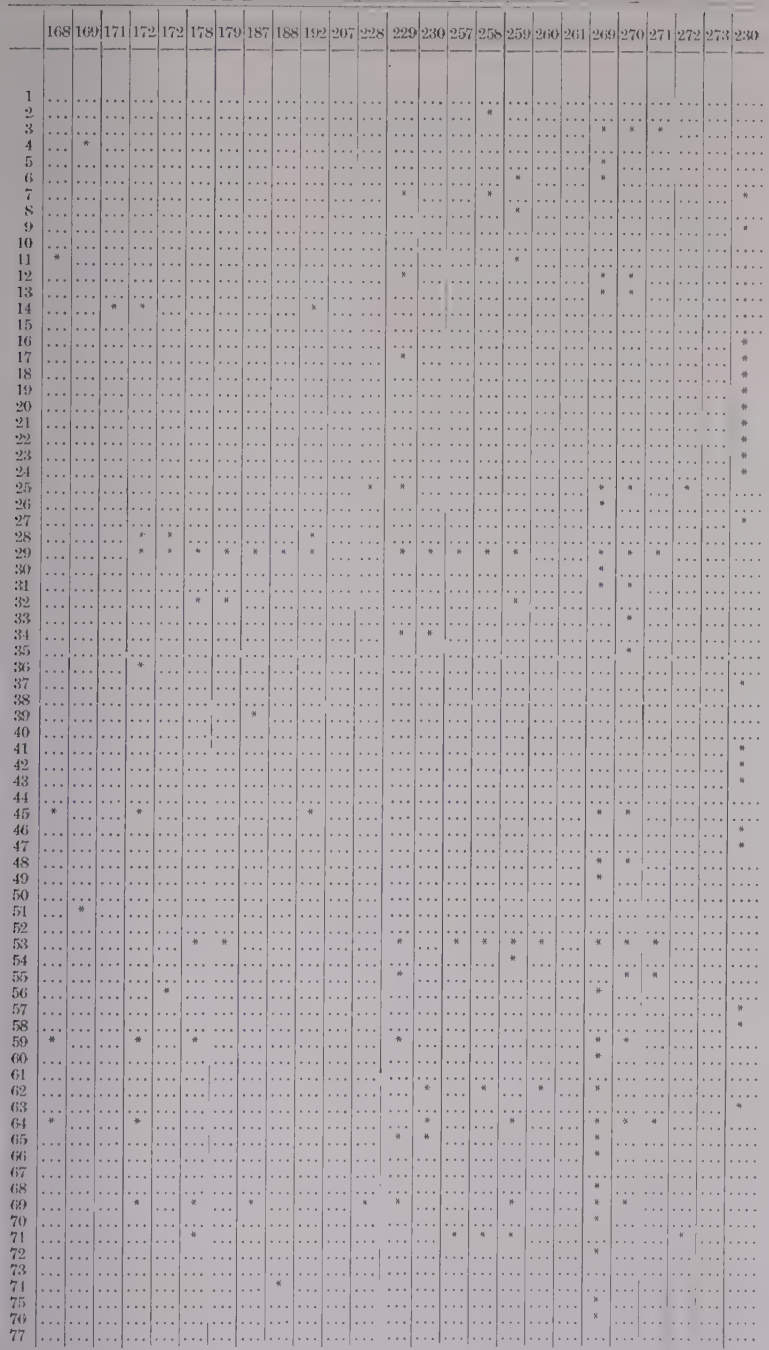
* From Tertiary Faunal Horizons of Western Washington, University of Washington Publications in Geology, Vol. I, No. 1, pp. 28-31.


57
59
63
65
66
67
70
71
73
74
77
80
81
88
90
92
97
98
102
103
105
106
107
108
109
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77

	LIST OF SPECIES	9	10	12	13	24	25	29	43	44	45	53	54	56
	SCAPHAPODA													
78	Dentalium stramineum Gabb													
79	Dentalium conradi Dall		*	*	*		*						*	*
80	Dentalium porterensis Weaver													
	GASTEROPODA													
81	Acteocina chehalisensis Weaver													
82	Ampullina oregonensis Dall													
83	Brachysphingus clarki Weaver													
84	Bittium lincolnensis Weaver													
85	Calyptraea excentrica (Gabb)													
86	Calyptraea washingtonensis Weaver													
87	Calyptraea filosa (Gabb)											*	*	
88	Calyptraea inornata (Gabb)													
89	Cancellaria wynootcheensis Weaver													
90	Cancellaria washingtonensis Weaver													
91	Cancellaria condoni Anderson											*	*	
92	Cancellaria dalliana Anderson											*	*	
93	Chrysodomus washingtonensis Weaver													
94	Chrysodomus packardi Weaver													
95	Chrysodomus clallamensis Weaver													
96	Crepidula princeps Conrad												*	
97	Crepidula praerupta Conrad											*	*	
98	Caliostoma delazinensis Weaver								*					
99	Chlorastoma arnoldi Weaver								*					
100	Drillia chehalisensis (Arnold)								*					
101	Cylichnella petrosa Conrad								*					
102	Epitonium washingtonensis Weaver													
103	Epitonium condoni Dall													
104	Epitonium rugiferum Dall													
105	Exilia lincolnensis Weaver													
106	Exilia dickersoni Weaver													
107	Eudolium petrosum (Conrad)	*	*		*						*			
108	Fusinus stanfordensis (Arnold)												*	
109	Fusinus corpulentus (Conrad)													
110	Ficus wynootcheensis Weaver													
111	Ficus chehalisensis Weaver													
112	Ficus oregonensis Conrad													
113	Ficus clallamensis Weaver													
114	Hemifusus washingtonensis Weaver													
115	Molopophorous gabbi Dall													
116	Molopophorous biplicata (Gabb)													
117	Molopophorous lincolnensis Weaver													
118	Miopleiona indurata Conrad													
119	Mesalia lincolnensis Weaver													
120	Nassa chehalisensis Weaver													
121	Nassa andersoni Weaver													
122	Nassa arnoldi Anderson													
123	Natica oregonensis Conrad	*			*						*	*	*	*
124	Natica washingtonensis Weaver													
125	Natica lincolnensis Weaver													
126	Natica lewisii (Gould)													
127	Natica olympidii Reagan													
128	Natica saxea Conrad													
129	Olivella pedroana Conrad													
130	Phalium aequisulcatum Dall													
131	Pisania clallamensis Weaver													
132	Scaphander washingtonensis Weaver													
133	Scaphander oregonensis Dall													
134	Strepsidura oregonensis Dall													
135	Strepsidura californica Arnold													
136	Sinum scopulosum Conrad													
137	Turris perissolaxoides Arnold													
138	Turris thurstonensis Weaver													
139	Turris packardi Weaver													
140	Turris dickersoni Weaver													
141	Turris kincaidi Weaver													
142	Turris clallamensis Weaver													
143	Turris wynoocheensis Weaver													
144	Turcicula washingtonensis Dall	*	*		*									
145	Turritella oregonensis Conrad													
146	Turritella porterensis Weaver													
147	Turritella blakeleyensis Weaver				*									
148	Turritella newcombei Merriam	*	*	*										
149	Brachyuran remains													
150	Aturia angustata Conrad		*										*	
151	Foraminfera sp.													
152	Sharks teeth													
153	Hemithyris astoriana Dall													
154	Terebratula oakvillensis Weaver	*		*										
155	Terebratalia occidentalis Dall	*		*										

	57	59	63	65	66	67	70	71	73	74	77	80	81	88	90	92	97	98	102	103	105	106	107	108	109
78																									
79	*		*		*	*	*		*	*		*	*		*	*						*	*		
80																									
81																									
82																									
83																									
84																									
85																									
86																									
87																									
88																									
89																									
90																									
91																									
92																									
93																									
94																									
95																									
96																					*	*			
97																									
98																									
99																									
100														*											
101																									
102																									
103																									
104																						*			
105																									
106																									
107																									
108																									
109																									
110																									
111																									
112																						*			*
113																									
114																									
115	*						*																		
116			*	*																					
117																									
118																						*			
119																									
120																									
121																									
122																									
123	*	*	*		*	*	*							*	*	*		*			*	*			
124																									
125																									
126																									
127																									
128																									
129																									
130																									
131																									
132																									
133																					*	*		*	
134	*																								
135																									
136																									
137																									
138																									
139																									
140																									
141																									
142																									
143																									
144																									
145																									
146																									
147																									
148																									
149													*				*								
150																									
151																									
152																									
153																									
154																									
155																									

	LIST OF SPECIES	128	129	130	145	155	156	157	158	159	164	165	167
	PELECYPODA												
1	Acila shumardi Dall				*	*				*			
2	Acila gettysburgensis Reagan												
3	Acila conradi Meek												*
4	Anomia subcostata Conrad												
5	Area trilineata Conrad				*								
6	Arca montereyana Osmont												
7	Cardium iorenzanum (Arnold)											*	
8	Cardium coosensis Dall												
9	Cardium lincolnensis Weaver												
10	Cardium vaqueroensis Arnold												
11	Chione securis (Shumard)												
12	Chione clallamensis Reagan												
13	Chione olympidea Reagan												
14	Chione catheartensis Weaver					*	*	*			*		
15	Chione temblorensis Anderson												
16	Callocallista arnoldi Weaver												
17	Crenella porterensis Weaver				*						*		
18	Crassatellites washingtonensis Weaver												
19	Crassatellites cowlitzensis Weaver												
20	Crassatellites lincolnensis Weaver												
21	Crenella washingtonensis Weaver												
22	Glycimeris chehalisensis Weaver												
23	Leda washingtonensis Weaver												
24	Leda lincolnensis Weaver												
25	Leda chehalisensis Weaver												
26	Leda oschsneri Anderson												
27	Macrocallista pittsburgensis Dall												
28	Macrocallista vespertina Conrad					*	*	*			*		
29	Marcia oregonensis (Conrad)					*				*			
30	Macoma secta Conrad												
31	Macoma nasuta Conrad												
32	Macoma calcaria Gmelin					*							*
33	Macoma clallamensis Reagan												
34	Macoma wynoocheensis Weaver												
35	Modiolus directus Dall				*								
36	Modiolus inflatus Dall				*								
37	Malletia chehalisensis Arnold									*			
38	Mytillus mathewsoni Gabb												
39	Mytillus sammamishensis Weaver							*					
40	Mytillus snohomishensis Weaver		*										
41	Nucula washingtonensis Weaver												
42	Ostraea veatchii Gabb												
43	Ostraea lincolensis Weaver												
44	Ostraea idraensis Gabb												
45	Panope generosa (Gould)					*	*	*					
46	Pandora washingtonensis Weaver												
47	Pitaria dalli Weaver												
48	Pecten propatulus Conrad												
49	Pecten fucanus Arnold												
50	Pecten peckhami Gabb												
51	Pecten porterensis Weaver												
52	Pecten aloekamanensis Weaver												
53	Phacoides actutilineatus (Conrad)				*						*		
54	Phacoides annulatus Reeves												
55	Solemya ventricostata Conrad				*								
56	Solen curtus Conrad				*		*	*	*				*
57	Solen lincolnensis Weaver												
58	Solen parallelus Gabb												
59	Spisula albaria (Conrad)						*						
60	Spisula catilliformis Conrad												
61	Tapes staleyi Gabb												
62	Tellina obruta Conrad												
63	Tellina lincolnensis Weaver												
64	Tellina oregonensis Conrad					*	*	*	*			*	*
65	Tellina aretata Conrad												
66	Tellina conjesta Conrad												
67	Tellina nuculana Dall												
68	Tellina nevadensis Anderson												
69	Thracia trapezoidea Conrad	*			*						*		
70	Thracia oregonensis Dall												
71	Thyasira bisecta (Conrad)										*		
72	Venericardia subtenta (Conrad)												
73	Venericardia chehalisensis Weaver												
74	Yoldia oregona Shumard												
75	Yoldia impressa Conrad												
76	Yoldia submontereyensis Arnold												
77	Yoldia sammamishensis Weaver		*										


168
169
171
172
172
178
179
187
188
192
207
228
229
230
257
258
259
260
261
269
270
271
272
273
230

	LIST OF SPECIES	128	129	130	145	155	156	157	158	159	164	165	167
	SCAPHAPODA												
78	Dentalium stramineum Gabb												
79	Dentalium conradi Dall					*					*	*	*
80	Dentalium porterensis Weaver												
	GASTEROPODA												
81	Acteocina chehalisensis Weaver												
82	Ampullina oregonensis Dall												
83	Brachysphingus clarki Weaver												
84	Bittium lincolnensis Weaver												
85	Calyptraea excentrica (Gabb)												
86	Calyptraea washingtonensis Weaver												
87	Calyptraea filosa (Gabb)												
88	Calyptraea inornata (Gabb)									*			
89	Cancellaria wynootcheensis Weaver												
90	Cancellaria washingtonensis Weaver												
91	Cancellaria condoni Anderson												
92	Cancellaria dalliana Anderson												
93	Chrysodomus washingtonensis Weaver												
94	Chrysodomus packardi Weaver												
95	Chrysodomus clallamensis Weaver												
96	Crepidula princeps Conrad					*	*			*			
97	Crepidula praerupta Conrad												
98	Caliostoma delazinensis Weaver												
99	Chlorastoma arnoldi Weaver												
100	Drillia chehalisensis (Arnold)												
101	Cylichnella petrosa Conrad												
102	Epitonium washingtonensis Weaver												
103	Epitonium condoni Dall									*		*	
104	Epitonium rugiferum Dall									*			
105	Exilia lincolnensis Weaver												
106	Exilia dickersoni Weaver												
107	Eudolium petrosum (Conrad)			*						*	*		
108	Fusinus stanfordensis (Arnold)									*			
109	Fusinus corpulentus (Conrad)												
110	Ficus wynootcheensis Weaver												
111	Ficus chehalisensis Weaver												
112	Ficus oregonensis Conrad												
113	Ficus clallamensis Weaver												
114	Hemifusus washingtonensis Weaver												
115	Molopophorous gabbi Dall									*			
116	Molopophorous biplicata (Gabb)												
117	Molopophorous lincolnensis Weaver												
118	Mioplelona indurata Conrad										*		
119	Mesalia lincolnensis Weaver												
120	Nassa chehalisensis Weaver												
121	Nassa andersoni Weaver												
122	Nassa arnoldi Anderson												
123	Natica oregonensis Conrad				*	*	*			*	*	*	
124	Natica washingtonensis Weaver												
125	Natica lincolnensis Weaver												
126	Natica lewisii (Gould)												
127	Natica olympidii Reagan												
128	Natica saxea Conrad												
129	Olivella pedroana Conrad												
130	Phalium aequisulcatum Dall												
131	Pisania clallamensis Weaver												
132	Scaphander washingtonensis Weaver										*	*	*
133	Scaphander oregonensis Dall												
134	Strepsidura oregonensis Dall									*			*
135	Strepsidura californica Arnold												
136	Sinum scopulosum Conrad												
137	Turris perissolaxoides Arnold												
138	Turris thurstonensis Weaver												
139	Turris packardi Weaver												
140	Turris dickersoni Weaver												
141	Turris kincaidi Weaver												
142	Turris clallamensis Weaver												
143	Turris wynoocheensis Weaver												
144	Turcicula washingtonensis Dall				*						*		
145	Turritella oregonensis Conrad												
146	Turritella porterensis Weaver												
147	Turritella blakeleyensis Weaver				*						*		
148	Turritella newcombei Merriam												
149	Brachyuran remains												
150	Aturia angustata Conrad				*						*		
151	Foraminfera sp.												
152	Sharks teeth												
153	Hemithyris astoriana Dall												
154	Terebratula oakvillensis Weaver												
155	Terebratalia occidentalis Dall												

	168	169	171	172	172	178	179	187	188	192	207	228	229	230	257	258	259	260	261	269	270	271	272	273	230
78																									*
79	*					*	*						*		*		*			*	*				*
80																									
81																									*
82									*				*	*											
83																									*
84																									*
85																									*
86																									
87																									
88																	*			*					
89												*					*								
90																									*
91																				*					
92																				*					
93																									*
94																									*
95																					*				
96					*																*				
97																				*					
98																									
99																									
100																									*
101																									*
102																									
103																									
104																									*
105																									*
106																									*
107	*									*									*		*	*			
108							*										*			*					
109																	*			*					
110													*												
111													*												
112																									
113																	*				*				
114																									*
115																									
116																									
117																									*
118																									
119																									*
120																									*
121																									
122																									
123	*									*	*														
124																									*
125																									*
126																									*
127															*		*								
128													*	*						*	*				
129																									*
130																	*				*				
131																									
132																									*
133																									
134				*				*																	
135																									*
136																									
137																*									*
138																									*
139																									*
140																									*
141																									*
142																									
143																									
144																									
145																*	*								
146																									*
147																									
148																		*							
149							*																		
150														*			*								
151																							*		
152																									*
153																									*
154		*																							
155																									

Oligocene Sandstone Exposed at the Boat Landing on Tatoosh Island.

LITHOLOGY.

The rock materials composing the Oligocene of western Washington are almost entirely of marine sedimentary origin. Interbedded lavas and tuffs are absent except on the north side of Columbia River in Pacific County. The sedimentary rocks consist of shales and sandy shales together with minor amounts of sandstones and conglomerates. A microscopic examination of these materials shows them to be in part derived from older igneous rocks. A considerable quantity of ash is present but always mixed with clayey material. The source of the tuffaceous materials was presumably from volcanic sources in the Cascades or eastern Washington. In northern Wahkiakum County andesitic flows were being deposited in marine embayments near the shore. Evidence for this is to be found in the sections exposed along the canyon of Nasel River.

The conglomerates occurring within the Oligocene of Seattle and at the entrance to the Bremerton Navy Yard are made up of pebbles ranging from the size of a pea to a foot or more in diameter. They are rounded and waterworn and composed in part of andesite and basalt and in part of sandstones and shales occurring within the formation. Pebbles made of quartzite and granite or diorite are very rare.

At the western end of Cape Flattery there are enormous belts of conglomerate in which the boulders are often over four feet in diameter. Commonly they are angular and only partially waterworn. They are in part composed of rocks which are not known to occur within the Olympic Peninsula but which do occur on Vancouver Island. The most common are quartzite, slate, schist and intrusive diorites and gabbros.

STRATIGRAPHY.

The more detailed facts concerning the stratigraphy are given in the description of the different districts in which the Oligocene deposits occur. It is not always possible to deter-

mine in the different sections just where the boundaries should be drawn between the three faunal zones or horizons.

In the vicinity of Lincoln Creek, west of Centralia, massive sandy shales outcrop along the south bank of Chehalis River. Very good exposures have been made in the cuts of the O.-W. R. R. & N. Co. The beds are dipping at a very low angle to the west and southwest. Interbedded with the sandy shales are narrow bands of clay shale. Often the sandy shales grade into a shaly sandstone. To the north of Chehalis River Eocene sandstones outcrop at Grand Mound. The Oligocene beds at Lincoln Creek rest upon the Eocene sandstones but the contact relations are obscure. Presumably they are unconformable. The total thickness of the lower Oligocene strata in the Lincoln Creek section is near 1,000 feet.

In the region where Porter Creek joins Chehalis River, near the town of Porter, the total thickness of the Oligocene sediments is about 2,000 feet. The section represents the shales and shaly sandstones exposed from the base of the section three miles north of Porter to the center of the syncline three miles west of Porter. These strata contain a fauna which has been designated as the Turritella porterensis Zone. It is possible that the lower 500 feet of the section may belong to the Lincoln Horizon or Molopophorous lincolnensis Zone.

In the Puget Sound region a section has been constructed at the entrance to the Bremerton Navy Yard. The district involved may be referred to on Plate XXIV. The strata are entirely of sedimentary origin. The Eocene basalts upon which the Oligocene sediments rest are exposed two miles southwest of Bremerton, on the west shore of Sinclair Inlet. The contact between the basalt and the base of the Oligocene is covered with deposits of glacial drift. The lowermost beds occur at Orchard Point. The upper beds outcrop on the north side of Blakeley Harbor. The total measured thickness of the Oligocene in this section is approximately 8,900 feet.

Oligocene Sandstone Exposed on the North Shores of Cape Flattery. Tatoosh Island in the Background.

Top of Section.	*Feet.*
(A) Massive coarse grained conglomeratic standstones, containing numerous lenticular bands of conglomerate. Occasional narrow bands of clay shale are interbedded. The eastward continuation of the conglomerates appear in the outcrops at Blakeley Rock. The beds persistently dip to the north at a very steep angle and extend as outcrops from the north shore of Blakeley Harbor northward for 1,500 feet	1300
(B) Sandy shales exposed beneath the waters of Blakeley Harbor	1400
(C) Brownish gray massive to slightly bedded shales as exposed along the south shore of Blakeley Harbor for a distance of one-half mile northwesterly. Five hundred feet stratigraphically above the beds exposed at Restoration Point is an excellent fossil locality	2400
(D) Shaly sandstones grading in places into a sandy shale. Bedding planes sometimes well defined. The top of this member is situated at Restoration Point	1200
(E) Shaly sandstone gradually becoming more sandy in depth. Bedding planes very distinct	450
(F) Massive sandy shales. Bedding planes distinct	350
(G) Massive brownish gray coarse grained conglomeratic sandstones interbedded with bands of coarse conglomerates. Many of the pebbles of the conglomerate are composed of basalt and shale	1800
Total thickness	8900

The above described beds also occur in part in the exposures within the City of Seattle and in the Newcastle Hills. Fossils are fairly abundant in these strata and belong to the Acila gettysburgensis Zone.

One of the most complete sections within the state occurs at Cape Flattery and along the Strait of Juan de Fuca. Approximately 15,000 feet of Oligocene sediments have been deposited. The basal beds are largely shales which have been badly contorted in places. Above these are massive conglomerates forming the point of the cape. The upper part of the section is composed of alternating shales and sandstones. The detail of this area may be seen on Plate XVII.

The following section is involved in Cape Flattery between the basal beds at Waatch Slough and the upper beds as exposed between Neah Bay and Sekiu River.

Top of Cape Flattery Section.	*Feet.*
Massive sandstone	700
Shale, but mostly covered	900
Massive sandstone	175
Shale, but mostly concealed	900
Massive sandstone	300
Concealed	500

Top of Cape Flattery Section.	*Feet*
Massive brown sandstone	300
Alternating beds of shale and sandstone	1200
Sandstone	200
Conglomerate	30
Sandstone	50
Conglomerate	50
Conglomerate and shale	500
Coarse conglomerate	300
Shale	700
Alternating beds of shale, sandstone and conglomerate	200
Massive sandy conglomerate	175
Hard flinty shale	200
Alternating shale and sandstone	300
Interbedded conglomerate and massive sandstone	450
Massive conglomerate	30
Massive sandstone and intercalated conglomerate lenses	300
Sandy conglomerate as exposed at the Cape	1400
Interbedded shale and sandstone	150
Shale, but mostly concealed	500
Banded sandy shale	200
Interbedded conglomerate and sandstone	250
Shale	350
Gritty sandstone with small amounts of interbedded shale	250
Shale	1200
Banded brown sandstone	100
Total thickness	12,860
Base of Cape Flattery Section.	

CONDITIONS OF DEPOSITION.

The Oligocene deposits of western Washington were entirely laid down in marine embayments. The character of faunas as well as the lithology of the sediments indicates deposition in moderately deep water. During the Oligocene the Cascade Mountains were not in existence. Their present site was a land area occupied in part by small fresh water lakes. Volcanic activity was more or less continuously taking place and the finer ashes may have in part been carried by the winds and dropped in the marine waters to the west. The northern Cascades were possibly much higher in elevation than the lake region of the central and southern Cascades. Presumably this region was being drained to the embayments of the ocean by streams heading in British Columbia or in eastern Washington. A considerable part of the sediments which forms the marine Oligocene deposits may have been derived from this area and have been transported westerly by stream action.

Interbedded Sandstones and Shales of Oligocene Age Exposed on the South Shore of Cape Flattery Half Way Between the Cape and Waatch Slough.

The Olympic Mountains and Vancouver Island were probably land areas. The Olympics were at least 1,000 feet lower in elevation than at present as marine deposits occur at that elevation where the wagon road from Clallam Bay to Forks crosses the main divide. Presumably the region had been partly reduced to a peneplain during the Cretaceous and Eocene and during the Oligocene the Strait of Juan de Fuca was depressed allowing marine sediments to form upon the submerged borders of the peneplain.

There are insufficient exposures to the Oligocene sediments to determine definitely the successive extent of the seas or embayments during the epoch. Sediments containing the Acila gettysburgensis Zone are much more widely distributed and are much thicker than those of the two lower zones. Apparently there was a partial withdrawal of the seas at the close of the Eocene and new invasion at the opening of the Oligocene. The embayments in which the Lincoln and Porter horizons were deposited were restricted in area and possibly did not cover the Puget Sound Basin area. During the upper Oligocene the larger part of western Washington west of the foothills of the Cascades was covered with the waters of the ocean. There may possibly have been a low land area connecting the Cascades with the Olympics in Pierce and southern Kitsap counties. This problem is still unsolved.

At the close of the Oligocene there was an emergence over a large portion of western Washington and all of the Puget Sound Basin became a land area. Embayments were still in existence in the Strait of Juan de Fuca region as well as in southwestern Washington.

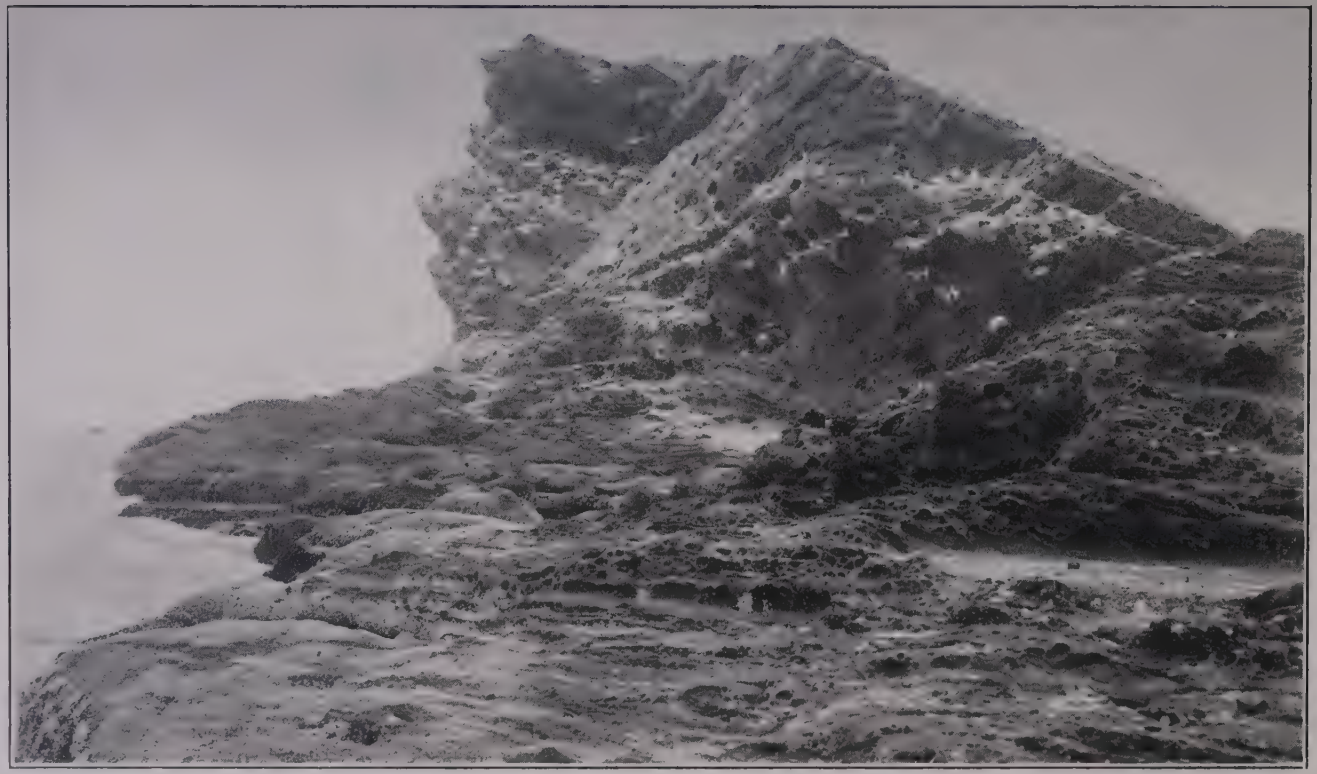
For purposes of detailed description western Washington may be divided into several provinces. The following divisions will be used in the discussion of the Oligocene: King County-Restoration Point Area; Cape Flattery-Strait of Juan de Fuca Area; Quimper Peninsula Area; Grays Harbor Area and Columbia River Area.

KING COUNTY—RESTORATION POINT AREA.

GEOGRAPHIC DISTRIBUTION.

There is a prominent spur of the Cascade Mountains in King County between Snoqualmie and Green rivers which extends westerly to Lake Washington. It crosses Puget Sound Basin in part as a sub-glacial and in part as a submarine ridge. The rocks forming the ridge are of Eocene and Oligocene age. Within the Puget Sound Basin they are exposed in Issaquah Mountain, Newcastle Hills, the low hills of South Seattle and Alki Point, the low rock cliffs at the entrance to the Bremerton Navy Yard, the Bald Hills of central Kitsap County and the foothills of the Olympic Mountains between the Duckabush and Quilcene rivers. The greater portion of this ridge is buried beneath an enormous deposit of glacial drift.

The core and south flank of the ridge and spur are composed chiefly of Eocene lavas and sedimentary rocks. The north flank is in part composed of Oligocene sedimentary rocks. The most easterly Oligocene exposures occur on the eastern side of Lake Sammamish, in Section 16, Township 24 North, Range 6 East in the side of a small creek. Outcrops also appear in the logging road cuts and small canyons on the divide between Coal Creek and Lake Sammammish. Farther west there are exposures south of Kirkland, east of Mercer Slough. The same rocks are well developed around the shores of Bailey Peninsula and from that point southward to Rainier Beach on the west side of Lake Washington. Similar exposures of the same formation have been made in the street excavations of Columbia City, South Seattle and Georgetown. At Alki Point Oligocene sandstones and shales occur tilted almost vertically and form a low marine terrace about 15 feet above sea level. The rocks are exposed along the beach for a distance of approximately 1,500 feet. Similar low rock terraces occur along the south shores of Bainbridge Island as well as on the opposite shore of Rich Passage. The same formation appears six miles westerly along the shores of the narrow inlet between Bremerton and Silverdale. No more exposures occur as far as the



Coarse Grained Oligocene Sandstones and Conglomerates Showing Cavernous Weathering as Exposed on an Island on the South Side of Cape Flattery.

south end of the Quimper Peninsula. East of Everett and south of Snohomish, at Fiddler Bluff, shales and sandstones of Oligocene age are exposed in the railroad and wagon road cuts. The surface formations on all sides of these outcrops for many miles are composed entirely of glacial drift.

STRATIGRAPHY.

The most complete section of the Oligocene deposits within the Puget Sound Basin is to be found at the entrance to the Bremerton Navy Yard. One generalized section has already been described in the general discussion of the Oligocene of western Washington. This section was constructed along the line B-B′, Plate IV.

The westerly continuation of the strata as exposed in section B-B′ reappear in the cross section A-A′. The upper beds exposed at Point Glover appear to be the equivalent of the beds in member (C) of the section B-B′. The extreme upper portion of member (G) as exposed at Orchard Point is the westerly continuation of the narrow conglomeratic layers occurring east of Bean Point on the south end of Bainbridge Island. The conglomerates outcropping at Quarry Point are the equivalent of those exposed at Middle Point. From Middle Point the same beds cross Rich Passage and appear in the cliffs at Fort Ward on the south shore of Bainbridge Island. Here they become less conglomeratic and more sandy. Near Restoration Point they are the equivalent of the upper portion of member (D). The shales and sandstones exposed between Point Glover and Middle Point are correlated with the sandy shales in member (C). The conglomerates in member (A) and the shales in member (B) do not appear on the south side of Rich Passage. It is possible that the conglomeratic sandstones and interbedded shales exposed near Tracyton and Phinney Point are the equivalent of members (A) and (B). The following stratigraphic section has been measured between the basal beds at Orchard Point and the higher beds exposed at Point Glover:

Top of Section at Point Glover.	*Feet.*
Massive sandy shale with poorly defined bedding planes	150
Shaly sandstone	70
Brownish gray sandy clay shale	500
Massive brown sandstone	100
Gray sandy shale	45
Brown massive coarse grained sandstone	60
Interbedded shale and sandstone, shale predominating	140
Massive sandstone	80
Thickly bedded shale	200
Alternating beds of thinly bedded shales and sandstone	520
Banded shale and sandstone, shale predominating	40
Banded shale and sandstone	20
Thinly bedded gray shale	70
Massive brownish gray sandstone	40
Thinly bedded shale	30
Massive brown sandstone	300
Mainly shale, with a few narrow bands of interbedded sandstone	200
Mainly sandstone, with a few narrow bands of interbedded shale	30
Mainly clay shale	900
Massive brown sandstone	65
Alternating layers of thinly bedded sandstones and shales with occasional bands of sandstone four to five feet in thickness	90
Massive brown sandstone, slightly banded	75
Banded shale	10
Thinly bedded shaly sandstone	40
Alternating bands of thinly bedded shale and sandstone	75
Massive brown sandstone	20
Massive brown gritty sandstone	35
Gray shale possessing well defined bedding	100
Massive brown sandstone containing bands of shale	30
Mostly shale with a few bands of interbedded sandstones; strata largely concealed	1800
Thinly bedded shale somewhat massive in places and containing occasional bands of sandstone averaging one foot in thickness	320
Massive brownish gray sandstone containing pebbly and conglomeratic bands	1400
Massive conglomerates composed of pebbles ranging up to two feet in diameter and composed in part of altered basalt	15
Massive gritty sandstone	60
Conglomerate	15
Massive gritty brown sandstone—these are the lowest strata exposed in the Bremerton Inlet area	70
Thickness	7615

In other portions of the Puget Sound area only partial sections can be measured. The northern and central parts of Seattle are composed entirely of deposits of glacial drift of great thickness. The southern portion of the city is in part built upon bed rock formations of Oligocene age. A thin layer of drift is mantled over much of this. Over 1,000 feet of sand-

stones and shales outcrop in the eastern wall of Duwamish Valley between Brandon Street and Georgetown. To the north the bed rock surface passes rapidly below sea level and is covered with over 800 feet of drift. To the south of Georgetown bedrock does not reappear for a distance of eight miles. Somewhere within this interval the contact between the Oligocene and Eocene formations lies buried.

One mile south of Georgetown, at South Park, on the west side of Duwamish River, three small rounded hills of sandstone and shale project through the alluvial covered floor of Duwamish Valley. These exposures together with those at Duwamish Station and Georgetown indicate that Oligocene bedrock exposures do not exist very deep below the floor of the valley.

In the street cuts of Columbia City, in South Seattle, shales and sandstones are exposed having a measured thickness of over 2,000 feet. A similar section exists to the east on the Bailey Peninsula where the deposits are in part composed of conglomerates. The strata outcropping in both of these localities are the eastern extension of those exposed at Georgetown as well as at the entrance to the Bremerton Navy Yard.

GEOLOGIC STRUCTURE.

In the discussion of the Eocene formations in King County a predominating anticlinal structure was described as trending east and west through South Seattle. The core and south flank was described as being composed of lavas and Eocene sediments. The north flank of the anticline is in part made up of Oligocene sandstones and shales which have just been described.

The principal structure consists of a predominating anticlinal axis referred to in this report as the Newcastle anticlinal axis, Plate IV, trending in a somewhat sinuous fashion through the Newcastle Hills westerly into South Seattle. It can be definitely traced from a point three miles east of Issaquah where it extends southwesterly to a point south of the same town. It crosses Issaquah Creek, passes through Squak Mountain and

into the Newcastle Hills. The Eocene lavas forming the core of the anticline outcrop on the eastern shore of Lake Washington south of the mouth of Coal Creek. Mercer Island and a large portion of the hills south of Columbia City are composed mostly of glacial deposits. The probable position of the anticlinal axis has been drawn upon the map, Plate IV, from the structural evidence afforded by the occurrence of Oligocene shales and sandstones in Columbia City and the Bailey Peninsula.

Oligocene sediments are not known to occur on the south flank of the Newcastle anticline. It is possible that they may at one time have extended much farther to the south and have later been removed by erosion or the original shore line may have been not far south of the present Eocene-Oligocene contact. The westerly continuation of the anticlinal structure occurs in the Bald Hills of Kitsap County where it may be monoclinal.

The Oligocene sediments in the north flank of the anticline have been somewhat wrinkled and developed into minor folds. The axes of such folds have been inserted on Plate IV.

A broad synclinal fold with its axis pitching to the north has been formed in the region of Lake Sammamish. Its nose is about two miles south of the town of Issaquah. The strata involved in its eastern limb are exposed to the east of Issaquah at Grand Ridge and to the north in Section 13, Township 24 North, Range 6 East. They have a strike of North 60 East and dip to the northwest. The sandstones and shales forming the western limb of the fold outcrop in the vicinity of the Superior coal mine on Tibbett's Creek and westerly at Coal Creek and Newcastle. Observations taken in the rock tunnels of the Coal Creek mine and along Coal Creek give strikes ranging from North 85° West to North 55° West. The dip varies from 40° to 70° to the northeast.

A second synclinal fold has been formed in the vicinity of Columbia City and South Seattle. Its axis also pitches northerly. The strata involved in the eastern limb outcrop in the

western portion of Columbia City and along the shores of the Bailey Peninsula where the prevailing strike is North 70 East and the dip 60° to the northwest. The sandstones and shales exposed within and to the west of Columbia City form the western limb and have a prevailing strike North 70° West and a dip of 70° to the northeast. The structural conditions at the Bailey Peninsula and along Coal Creek suggest the presence of a minor anticlinal fold in the near vicinity of Mercer Island.

A third synclinal fold lies in Duwamish Valley. Its eastern limb is composed of strata exposed in the bluff along the eastern side of Duwamish Valley from Brandon Street to Georgetown. Between Brandon Street and the Archer Blower Iron Works the beds have a strike of North 25° East and a dip of 28° to the northwest. To the south in the vicinity of Georgetown the strike is more nearly north and south. South of Georgetown the strike is North 25° West and the dip 35° to the southwest. The nose of the fold is near Duwamish Station. The western limb is formed of rock outcrops in the three hills at South Park and Alki Point. At the former locality the strike is North 50° West and the dip 50° to the northeast. The hills between Duwamish Valley and Admiralty Inlet are entirely composed of deposits of glacial drift. The structural conditions on the eastern side of Duwamish Valley and in the western part of Columbia City indicate the existence of a minor anticline in the ridge between.

Excellent exposures of the Oligocene strata occur on the south shore of Bainbridge Island as well as to the south on the opposite shore. The structural relations may be seen on Plate XXIV. A minor anticlinal fold occurs between Point Glover and Middle Point on the south of Rich Passage. A small synclinal fold exists on the south end of Bainbridge Island between Pleasant Beach and Bean Point. From Point White westerly no Oligocene deposits are exposed as far as Tracyton. In the vicinity of Tracyton sandstones and shales outcrop along the water's edge for a distance of a mile. No further exposures

occur as far as the west side of Hood Canal with the exception of glacial drift.

To the north of the area described in both King and Kitsap counties no bedrock outcrops at the surface. The Oligocene formations in the north flank of the Newcastle anticline, from structural conditions occurring at the surface, must extend very deep. Presumably there is a major synclinal trough trending east and west and eight or ten miles to the north of the surface exposures. Such a trough does exist between Port Discovery Bay and Quilcene Bay in Jefferson County. The strata involved in the south flank of this trough are the westerly continuation of those exposed at the entrance to the Bremerton Navy Yard. Those on the north flank are probably the equivalent of deposits which are presumed to exist far below sea level in northern Kitsap and King counties.

Between Duwamish Station and Renton and easterly to Cedar River folds have been formed but the strata involved are of Eocene age. It is possible that small outliers of Oligocene sediments may exist but as yet they have not been discovered.

Fossil marine invertebrates are abundant and fairly well preserved in certain localities in this area. There is very little variation in the faunas from the upper to lower beds. They represent the Acila gettysburgensis Zone. The Molopophorous lincolnensis and Turritella porterensis zones are absent or at least have not as yet been recognized.

QUIMPER PENINSULA AREA.

GEOGRAPHIC DISTRIBUTION.

The Quimper Peninsula forms the extreme northeastern corner of the Olympic Peninsula. The surface exposures over most of this area consist of sands, clays and gravels of glacial origin. At several localities along the shore and in the small creek canyons there are exposures of lavas and sedimentary rocks of Eocene and Oligocene age. The former have been described in the previous chapter. From Hood Head on Admiralty Inlet a belt of Eocene lava and tuffs four miles wide

extends northwesterly across the peninsula to the south end of Port Discovery Bay. They continue as a narrower belt from the western shore of Port Discovery Bay to Sequim Bay. These rocks constitute the core or axis of an anticline which to the east in Kitsap County does not appear at the surface. Sandstones and shales of Oligocene age rest upon both the northeastern and southwestern flanks. The former outcrop at the water's edge along the shore of Oak Bay, Scow Bay, the southern part of Port Townsend Bay and the middle shores of Port Discovery Bay. The latter are exposed at the south end of Port Discovery Bay and along the cuts of the Port Townsend and Southern Railway as far as Quilcene. The area between the railroad and the central core of Eocene lavas is largely covered with glacial drift. To the southwest of Quilcene Eocene lavas reappear as the surface exposures where not covered with drift. The contacts as drawn upon Plate IV are provisional since they are in most places concealed beneath deposits of drift.

GEOLOGIC STRUCTURE.

A synclinal and an anticlinal fold constitute the predominant structural feature of this area. The approximate position of the anticlinal fold has been described. The synclinal fold is to the southwest of the former and trends from southeast to northwest. The trough is from six to eight miles in width but narrows from the southeast to northwest. The strata outcropping along the railroad from Quilcene to Port Townsend Bay form its southwestern limb. The sandstones and shales exposed from Crocker Lake to Fairmont on the shore of Port Discovery Bay are a part of the northeastern limb. This syncline is probably the northwestern continuation of the one in Kitsap and King counties lying north of the Newcastle anticline and buried beneath an enormous thickness of glacial drift. Its south limb is composed of strata which are an extension of the Oligocene at Bremerton Inlet, Seattle and the Newcastle Hills.

About five miles northeast of Quilcene sandstones outcrop on the wagon road to Dabop Bay. The hills on the west side

Sandstones and Conglomerates of Lower Miocene Age as Exposed East of Clallam Bay on the South Shore of the Strait of Juan de Fuca.

of Crocker Lake have excellent exposures of shale and sandstone. They strike northeast and southwest and seem to be passing around the nose of the syncline.

North of Hood Head partially stratified tuffs and intercalated lavas are dipping to the north at an agle of 28°. About one mile north of Olele Point Oligocene shales are resting upon the lavas and dipping north at an agle of 8°. From that point to the south end of Port Townsend Bay shales with alternating beds of sandstone have an average angle of dip to the north of 15°. Along the shores of the southern end of Port Townsend Bay and Scow Bay the sedimentary rocks are interbedded shales and sandstones.

On the eastern shores of Port Discovery Bay gray sandstones outcrop at the water's edge just north of Woodman Station. They are resting nearly flat but in places are slightly undulating. Massive clay shales are exposed on the opposite western shore of the bay.

Poorly preserved fossils occur scattered through the strata at different localities. They are most abundant north of Woodman Station on Port Discovery Bay and near the north end of Oak Bay. The species are somewhat different from those in the Acila gettysburgensis Zone and seem to have closer affinities with the Turritella porterensis and Molopophorous lincolnensis Zone.

CAPE FLATTERY-STRAIT OF JUAN DE FUCA AREA

GEOGRAPHIC DISTRIBUTION.

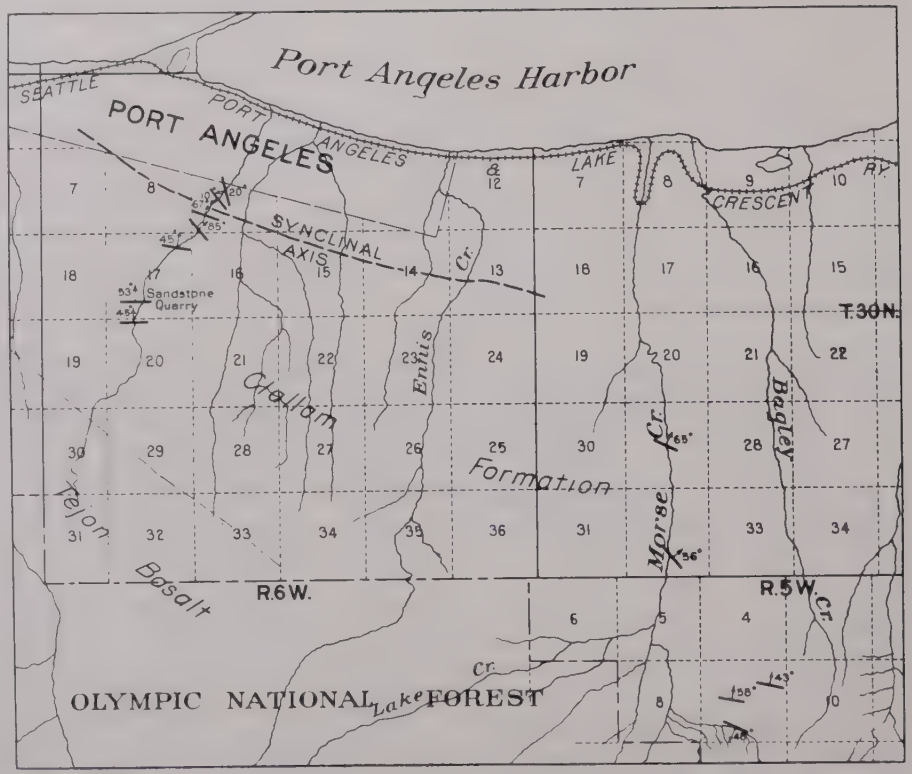
The area involved extends from Port Crescent westerly to Cape Flattery, a distance of fifty miles. The belt is six to eight miles in width. It forms the north coastal border of the Olympic Peninsula. The surface exposures are almost entirely composed of glacial drift. The Oligocene rock outcrops are confined to the shore line and the canyons of the creeks draining to the Strait of Juan de Fuca. With the exception of the divide extending to Cape Flattery the average elevation is 400 feet above sea level. The contact between the Eocene and Oligocene, which has been designated upon the map, Plate IV,

is provisional. On the coast south of Cape Flattery it can be definitely established one mile north of Portage Head. It occurs near the falls on Hoko River in Section 24, Township 31 North, Range 14 West. Between Hoko River and the ocean a detailed search has not been made. The region is heavily timbered and covered with glacial gravels. The contact crosses the Forks-Clallam Bay wagon road just south of the divide and continues westerly north of Solduck River to Lake Crescent. The line as drawn upon the map is only approximate and should not be accepted as accurate. Exposures of lava occur in the wagon road cuts on the north side of Lake Sutherland in Section 21, Township 30 North, Range 8 West. From Lake Sutherland the contact trends northwesterly and reaches the coast at a point two miles west of Port Crescent.

GEOLOGIC STRUCTURE.

Both the Oligocene and Eocene deposits on the north shore of the Olympic Peninsula are involved in a large synclinal trough the axis of which trends from Lake Sutherland northwesterly diagonally across the Strait of Juan de Fuca. The northeastern limb of it is represented as a narrow fringe on the opposite shore of Vancouver Island. The southwestern limb has just been described as forming the north border of the Olympic Peninsula. The strata involved within it are 19,000 feet thick, 15,000 feet of this amount consisting of shales and sandstones of Oligocene age. Above these there are 4,000 feet of lower Miocene sandstones and shales exposed on the shore of the Strait of Juan de Fuca between Pysht and Clallam Bay.

On the southwestern flank of the major syncline ten transverse minor anticlinal and synclinal folds have been developed between Crescent Bay and Cape Flattery. Their average trend is about North 15° East. The nose of the major syncline where the Oligocene beds rest upon the Eocene basalts is situated in Section 19, Township 30 North, Range 8 West. The axis of the syncline crosses the county wagon road in Section 6, Township 30 North, Range 9 West, and extends northwesterly, intersecting the coast one mile west of Gettysburg. The shales



Geologic and Structural Map Southwest of Port Angeles, Clallam County.

on the eastern limb have an average strike of North 60° West and dip to the southwest at an angle of 18°. The strata involved in the western limb have a prevailing strike of North 75° West with a dip ranging from 13° to 45° to the northeast. In the vicinity of the point where the synclinal axis emerges at the Strait of Juan de Fuca an anticlinal axis also emerges with a trend North 30° East. The strata forming the western limb of the anticline are exposed in the bluffs along the shore for a distance ten miles west of Gettysburg. The prevailing strike is North 60° East and the dip 13° to 45° to the northwest.

In the bluff just west of Twin River sandy shales occur striking nearly north and south with a dip of 15° to the west. Farther to the west the first exposures encountered are about one and one-half miles west of Deep Creek with a strike of North 30° West and a dip of 30° to the southeast. On the basis of this evidence and a similarity of the stratigraphic sections a synclinal trough is believed to trend nearly parallel to Deep River. A small anticline exists one and one-half miles east of Pysht. From Pysht to Clallam Bay the exposures along the shore of the strait are of lower Miocene age.

From the mouth of Sekiu River to Cape Flattery the strata are entirely of Oligocene age. The structure is mainly monoclinal. The sandstones and shales involved in the monocline are in reality the southwestern limb of the major syncline previously described. Observations taken on strike and dip along the Clallam Bay-Forks wagon road for a distance of five miles from Clallam Bay give an average strike of North 60° West and a dip of 40° to the northeast. On Pysht River in Section 23, Township 31 North, Range 12 West the strike is North 35° West and the dip 32° to the northeast. Two miles south of this point they begin to appear along the wagon road and continue to the main divide. In the western part of Section 26, Township 31 North, Range 12 West, the strike of the shales ranges from North 6° West to North 30° West with a dip of 45° to the northeast. Just south in Section 35 the strike becomes North 70° West and the dip 60° to the northeast.

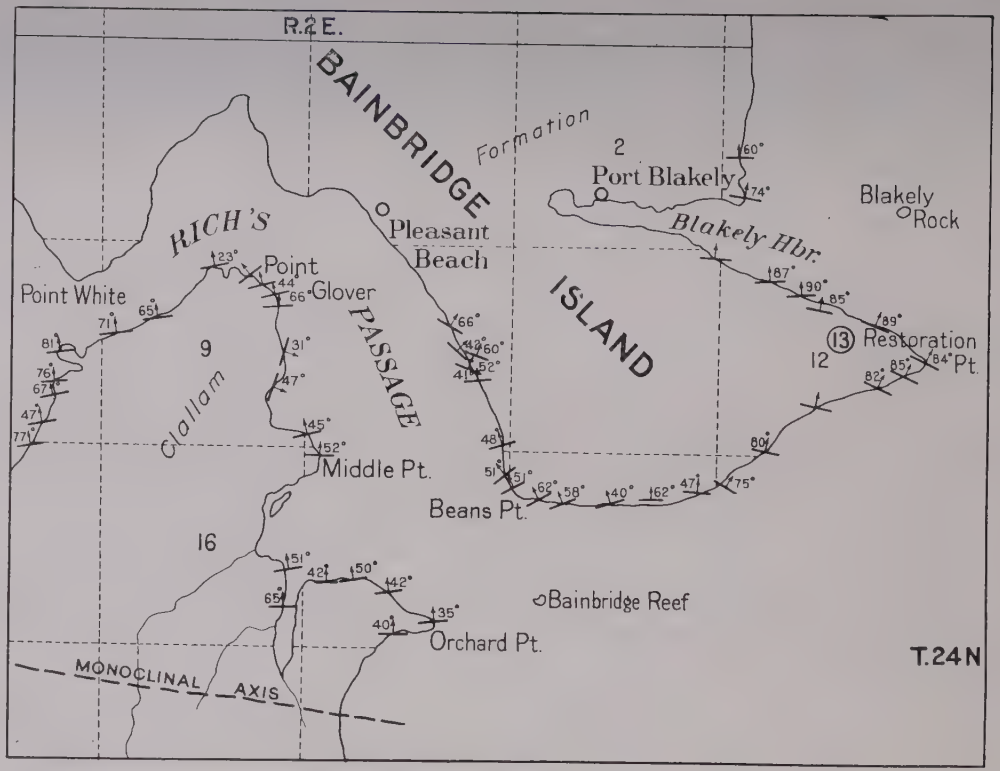
Along the shores of Cape Flattery the strike varies from North 70° West to North 30° West with a constant dip to the northeast ranging from 20° to 70°. At the extreme point of the cape the dip is nearly flat in places and on Tatoosh Island the strike is North 30° East and the dip 20° to the southeast. South of the cape near the mouth of Sooes River the strata have an average strike of North 45° West with a dip ranging from 20° to 80°. Observations taken in the cliffs along Waatch Slough conform in general to those around the shores of the cape.

Between Sooes River and Portage Head the Oligocene deposits are covered with Pleistocene sands and gravels, so that the structure cannot be determined. At Portage Head badly altered basalts of probable Eocene age form prominent outcrops. It is possible that a fault extends from the north end of this head southeasterly along the main divide. If so the Oligocene deposits may have been dropped to the north as a block. Between Portage Head and Point of the Arches, Oligocene strata outcrop along the beach for a distance of three miles. They have been folded into a synclinal trough whose axis trends North 45° West and intersects the coast line in Section 19, Township 32 North, Range 15 West. The strata forming the north limb strike North 35° West and dip at an agle of 65° to the southwest. Those in the south limb have a strike of North 40° West and dip 45° to the northeast. No determination has been made as to how far these deposits extend to the southeast.

The Oligocene deposits on the north shores of the Strait of Juan de Fuca opposite Cape Flattery outcrop at intervals from Sooke Bay westerly to Carmanah Point. They rest unconformably upon Carboniferous and Mesozoic metamorphics together with Eocene lavas and tuffs.

FAUNA.

The shales exposed between Crescent Bay and Gettysburg and along the north shores of Lake Crescent contain a small fauna more closely allied to the Turritella porterensis Zone



Geologic and Structural Map in the Vicinity of the Entrance to the Bremerton Navy Yard.

than to the Acila gettysburgensis Zone. The shales occurring along the shore south from Cape Flattery are presumably of the same horizon. The exposures between Twin and Pysht contain a fauna typical of the Acila gettysburgensis Zone. The strata are the equivalent of those in Kitsap and King counties. The fauna occurring in the shales and sandstones between Sekiu River and the extreme point of the Cape belong to the same zone. The massive sandstones and shales exposed between Pysht and Clallam contain a lower Miocene fauna. The contact relations between the lower Miocene and the Oligocene at Pysht and Clallam Bay are uncertain. There appears to be a fault contact just east of Pysht. Presumably the two formations are unconformable. At the time when the maps accompanying the report were made the strata containing the Acila gettysburgensis Zone and the Turritella porterensis Zone were thought by the writer to be lower Miocene. As a result, they, together with the Arca montereyana Zone as exposed between Pysht and Clallam Bay are included in the Clallam formation. In the revised grouping the Arca montereyana Zone or lower Miocene is not included within the Clallam formation. The Clallam formation as previously defined is restricted to the Oligocene marine deposits.

A list of the faunas occurring at the localities along the Strait of Juan de Fuca are given in the Faunal lists of the Oligocene on page 170.

GRAYS HARBOR AREA.

GEOGRAPHIC DISTRIBUTION.

The Oligocene deposits of the Grays Harbor area involve approximately 600 square miles of territory. They lie in contact with the overlying upper Miocene deposits and to the south and east with the Tejon formation. The area indicated upon Plate III as the Lincoln formation should also be grouped with the marine Oligocene for discussion. The larger part of the area is heavily covered with forest and such rock exposures as occur are usually deeply altered and converted into soil. The tracing of contacts upon the surface becomes exceedingly dif-

ficult. The contacts as designated upon Plate III are only approximate. Observations were made on the different creeks and the positions of contact noted where possible. Such points were connected by provisional contact lines. Large portions of this area are entirely devoid of surface rock exposures but wherever conditions warranted it the probable underlying bed rock formations were given the preference in mapping. Where it was impossible to determine the character of the underlying formations the surface gravels or sands were mapped.

Beginning at Grays Harbor and passing southerly, the contact of the Oligocene shales and sandstones may be seen on North River in the northwestern corner of Township 15 North, Range 9 West. South of this locality the exposures are concealed. The contact crosses Willapa River about halfway between South Bend and Raymond. To the north and south of the city of South Bend basaltic rock appears in places which are presumably of Eocene age. To the south of Raymond a survey was made up the south fork of Willapa River and the contact determined as indicated upon Plate III. Several basalt flows are intercalated with shales. Fossils are absent and the uppermost lava flow was chosen as the base of the Oligocene formations. From Trap Creek the contact swings more nearly east and follows the foothills about two miles south of the South Bend branch of the Northern Pacific Railway. In Willapa River at Holcomb there are basaltic tuffs and lavas whose stratigraphic position could not be definitely determined. The contact was drawn two miles south of Holcomb on the basis of finding a few species of Oligocene fossils on Trap Creek. A contact was observed in the cuts of the railway just west of Pluvius Station on the divide between the headwaters of Willapa and Chehalis rivers. From this point it swings northerly as an irregular line and follows roughly the divide between Chehalis and North rivers. It passes the headwaters of Vesta, Pioneer and Martin creeks on the southwest and Rock and Garrard creeks on the northeast. It continues on to the northwestern side of Chehalis Valley which it crosses near the junc-

tion of Rock and Cedar creeks. Thence it extends northwesterly until it disappears beneath the drift covered areas of Mason County.

Basalt occurs along the divide between Fall River and Wilson Creek in the northwest corner of Township 14 North, Range 6 West. This has been mapped as Eocene but may possibly be a Miocene flow. If so it lies in contact with the Eocene basalts to the east and cannot as yet be separated from them. The north limits of the Oligocene deposits lie in close proximity to Chehalis River. The contact crosses east of the town of Montesano and swings past Bitter Creek and Wynoochee River in the north central part of Township 18 North, Range 8 West. West of this place it turns south and crosses Chehalis River east of Cosmopolis.

The strata occurring in the south halves of Township 17 North, Ranges 7 and 8 West are in part lower Miocene. On Plate III it is included with the Clallam formation. Insufficient information is available to determine its areal limits.

GEOLOGIC STRUCTURE.

The Oligocene deposits of the Grays Harbor area have been folded into a series of nearly parallel anticlines and synclines trending approximately North 50° West. Three synclinal troughs have been developed. The most southerly of the three extends from the headwaters of Willapa River northwesterly to Grays Harbor. The south limb resting upon Eocene basalts, is composed of sandy shales and sandstones which near the town of Willapa have a strike nearly north and south and a dip varying from 10° to 20° to the east. Survey traverse lines were made up Mill Creek and the data obtained has been platted upon Plate III. The strata have an average strike of North 60° West and a dip of 20° to 30° to the northeast. Nearly all the observations recorded between Willapa and Francis show a prevailing northwest strike and a dip to the northeast. Rock exposures forming the north limb may be seen in the stream canyons on the road from Willapa to Brooklyn. The average strike is North 45° West and the dip 20° to the south-

east. Observations made on the same limb along North River in Township 16 North, Range 9 West show prevailing strikes of North 60° West and dips ranging from 18° to 34° to the southwest.

A second synclinal trough trends from the headwaters of North River northwesterly to Montesano. Both flanks are dipping at very low angles towards the axis and the trough itself is pitching to the north. South of Chehalis River in Township 17 North, Ranges 7 and 8 West, the strata become nearly flat and finally develop into four minor short folds all trending northwesterly. The eastern limb of the main trough may be cut off from the underlying basalts by a fault trending diagonally across Township 16 North, Range 6 West.

To the northwest of Montesano the Oligocene is fairly well exposed in places and while the strata are not sharply folded yet there are undulations which may be definitely traced as anticlinal and synclinal troughs. The positions of these folds have been designated upon Plate III.

Outcrops are well exposed along the O.-W. R. R. & N. Co. track between South Elma and Cosmopolis. The strata involved are presumably of lower Miocene age but they are grouped with the Clallam formation on Plate III. About three miles east of South Montesano an anticline crosses Chehalis River trending North 55° West. Exposures of the northeastern flank in the O.-W. R. R. & N. Co. cuts strike North 50° West and dip 15° to the northeast. In the southwestern limb the dip is 30° to the southwest.

Three miles west of this anticline and south of Montesano the nose of a synclinal trough has been developed. It pitches South 45° East. On the northeastern side of the synclinal nose the sandstones and shales strike North 50° West and dip 35° to the southwest. To the west the strike gradually becomes more westerly until due south of Montesano it swings around and becomes north and south, with a dip of 30° to the east. In the grade cuts on Clemmon's logging road in Sections 19 and 20, Township 17 North, Range 7 West, the average strike is North 60° West and the dip ranges from 15° to 25° to the northeast.

To the west of this synclinal axis a nearly parallel anticline crosses Chehalis River one-half mile east of Melbourne. It trends northwesterly and then turns and crosses Wynoochee River two miles south of its junction with Bitter Creek. Three miles farther west there is a synclinal trough and west of this the upper Miocene deposits rest upon the Oligocene and lower Miocene strata unconformably.

A small anticline crosses Wynoochee River in Section 16, Township 18 North, Range 8 West. The strata on the north flank dip at an angle ranging from 8° to 15° to the northeast while those on the south flank have a dip of 21° to the southwest. About one mile south a shallow syncline has been formed with a trend of approximately North 65° West.

In the southeastern part of Grays Harbor County a synclinal trough has been developed in the valley of Chehalis River from Oakville to Elma. It trends North 40° West and pitches to the northwest. The strata involved belong to the middle Oligocene or Turritella porterensis Zone. They are resting upon the Eocene basalts which are exposed at Oakville and in the Black Hills. On the east side of Chehalis River there are bluffs of sandy shale having a strike of North 30° East and a dip of 6° to 10° to the northwest. Three miles to the north, on Porter Creek, the dip increases to 40°. At this locality layers of basalt are interbedded with the sediments. No fossils occur and it is not certain whether the interbedded sediments are Oligocene or Eocene. To the northeast the Oligocene deposits are covered with sandstones and shales of upper Miocene age. The south limb of the syncline has a prevailing dip to the northeast, although in places as on Rock Creek in Section 17, Township 16 North, Range 5 West, it is nearly horizontal or undulating. On Lankner Creek in Sections 25 and 26, Township 17 North, Range 6 West, the shaly sandstones have a strike of North 60° West and a dip ranging from 10° to 16° to the northeast. North of Delazine Creek upper Miocene deposits overlie the Oligocene.

A small isolated exposure of lowermost Oligocene occurs in southwestern Thurston and northwestern Lewis counties. The area is designated upon Plate III as the Lincoln formation. More recent studies since the completion of the maps have proven that the Lincoln formation is lowermost Oligocene and represents the Molopophorous lincolnensis Zone or the Lincoln Horizon. The deposits are at least 800 feet thick and are involved in a northwesterly trending shallow trough. Observations taken on the strike and dip between Lincoln Creek and Helsing Junction show a prevailing dip ranging from 4° to 12° to the southwest. At a point three miles above the mouth of Lincoln Creek the strata are dipping to the northeast. For some distance west of Helsing Junction the predominant dip is to the east and northeast, at angles ranging from 60° to 40°. The approximate position of the axis of this trough has been designated upon Plate III.

A small exposure of sandy shale occurs in the banks of Olequa Creek two miles south and west of Winlock. The fossils collected belong to the Molopophorous lincolnensis Zone. The surrounding country is deeply buried with gravels and sand and the lack of surface rock outcrops prevents areal mapping. The strata have an average strike of North 20° West and a low dip to the northeast.

COLUMBIA RIVER AREA.

GEOGRAPHIC DISTRIBUTION.

The Oligocene and lower Miocene deposits have been mapped as the Clallam formation in this area. With more detailed field studies in the future it may be possible to make a separation. These deposits occupy a belt along the north side of Columbia River roughly 45 miles in length by 10 miles in width. The belt extends in a nearly east to west direction from the ocean to within ten miles of Cowlitz River. At the eastern end it is only two miles in width, while at Shoalwater Bay it is over 15 miles. The contacts in most places are only approximate. It is possible that some of the lavas occurring on Nasel River which have been mapped as Eocene are in reality Oligocene. The

northern contact has been drawn two miles north of the mouth of Nasel River at the base of the basaltic ridge. Oligocene shales outcrop at the mouth of the river and at various points along its course. Basalts also occur along the river at certain points. One of these is in Section 20, Township 11 North, Range 8 West in a deep canyon. The rock is an agglomeratic tuff with intercalated narrow tongues of lava. The lavas have been mapped as Eocene and the sedimentary rocks as Oligocene on the basis of faunas. Just above the mouth of Alder Creek there are a few poorly preserved fossils occurring in the tuffs which may be Oligocene. The Eocene-Oligocene contacts have been located on both the left and main forks of Grays River as well as on Skamokawa and Alockaman rivers. Marine Oligocene fossils occur in Section 6, Township 9 North, Range 4 West, on the west branch of Abernathy Creek. Sediments of a similar character containing a similar fauna occur on Germany Creek, seven miles from its mouth. Doubtless small patches as yet undetected exist farther to the east.

The south contact of the Oligocene and the underlying basalts crosses Alockaman River in Section 2, Township 9 North, Range 5 West. A narrow belt of basalt trends parallel to Columbia River from Skamokawa to Altoona. The contact with the Oligocene sediments on the north is indefinite. It is in part complicated by faulting.

Massive cliffs of basalt form the cape at the north entrance to Columbia River. Stratigraphically above the basalts are tuffs and interbedded shales containing lower Oligocene fossils. At Fort Columbia opposite Astoria, massive tuffs are exposed forming the core of an anticline. Shales and massive sandstones rest upon them. These are presumably Eocene but no fossils were found to prove their age. They may possibly be interbedded with the lower Oligocene sediments. No attempt has been made to differentiate them from the Clallam formation. Narrow dikes of diabase cut the Oligocene strata between Knappton and Grays Bay. One of the largest of these dikes

outcrops on the north shore of Columbia River in Section 11, Township 9 North, Range 9 West.

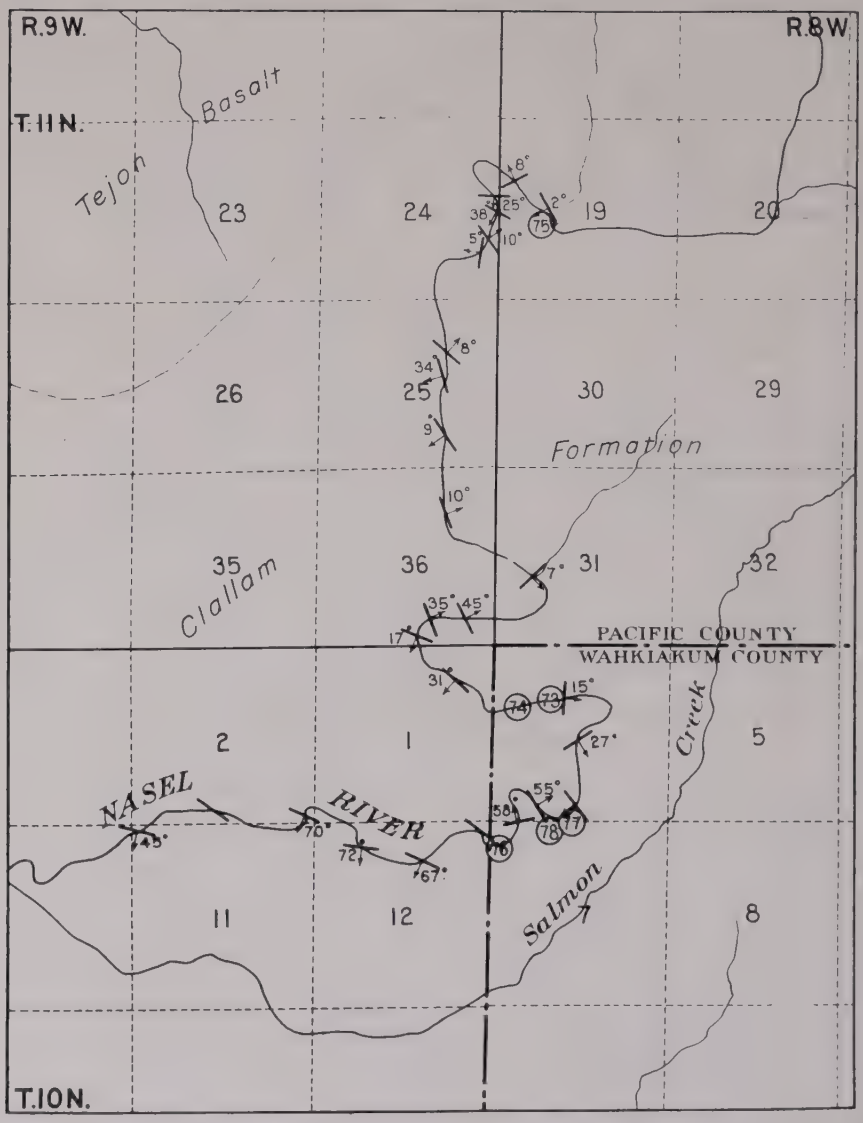
Basalts occur intercalated with the shales and sanstones exposed at the south end of Long Island in Shoalwater Bay as well as along the shores of Long Island Slough.

The Oligocene formations exposed in this area consist of massive sandy shales, and interbedded narrow bands of shale and sandstone. Some of the shale bands are thinly bedded and occasionally calcareous. East of Knappton on the north shore of Columbia River small nodules occur in the shale bands. These are decidedly calcareous and usually contain at their centers a small fossil or pebble. The surface rock exposures are usually deeply altered and often entirely converted to soil.

GEOLOGIC STRUCTURE.

The Oligocene and lower Miocene strata of this area have been folded into a trough-like basin extending nearly east and west. Within this trough subsidiary anticlinal and synclinal folds have been developed all of which have a prevailing northwest to southeast trend. In Wahkiakum and Cowlitz counties the axes of the folds have an average trend of North 60° West. To the west in Pacific County they swing more to the northwest. An examination of the cliffs along the north shore of Columbia River indicates a syncline to intersect the shore in Section 1, Township 9 North, Range 9 West. The intervening area northward to Nasel River is barren of outcrops of such character that observation on strike and dip can be obtained. The syncline probably crosses the river in Section 4, Township 10 North, Range 9 West. From observations taken along the shore of Columbia River west of Knappton an anticline seems to exist with a northwesterly trend toward Shoalwater Bay.

An examination of the small creeks emptying into Wallicut River indicates the presence of a syncline between Bear River and Ilwaco with a trend of North 35° West. The more prominent folds of this area have been inserted on Plate III. A more detailed examination of the district would probably show many other minor folds provided sufficient rock exposures could be found.



Geologic and Structural Map Along Portion of Nasel River, Pacific County.

CHAPTER V.

MIOCENE FORMATIONS.

GENERAL STATEMENT.

Recent faunal evidence indicates that a part of the deposits of western Washington formerly regarded by the writer as lower Miocene are in reality Oligocene. The extreme upper portion of the Clallam formation as designated upon Plate IV is characterized by the Arca montereyana fauna. The term Clallam formation is now restricted to the Oligocene and the Arca montereyana Zone or Wahkiakum Horizon is retained in the lower Miocene.

There is a marked unconformity between the formations of the lower and upper Miocene. The former occur in Clallam County between Pysht and Clallam Bay as well as in Grays Harbor County between Montesano and Cosmopolis. Exposures also are present in Wahkiakum County on Alockaman River twelve miles north of Cathlamet. The upper Miocene deposits are confined to the Grays Harbor region and a small area in southwestern Clallam County near the mouth of Quillayute River. The total maximum thickness of the Miocene sediments is not over 8,000 feet.

LOWER MIOCENE.

GEOGRAPHIC DISTRIBUTION.

The massive sandstones and shales outcropping along the shore of the Strait of Juan de Fuca between Pysht and Clallam Bay contain a fauna distinct from the older Oligocene faunas as well from the younger upper Miocene faunas. The rocks are predominantly massive brownish gray sandstones which in places become grits or conglomerates. They exhibit distinct cross-bedding and give the appearance of having been deposited partly in the form of sand dunes. Carbonaceous bands occur occasionally. In Section 25, Township 32 North, Range 12 West a coal seam is interbedded with the massive sandstones and has at former times been worked on a commercial scale. The lower Mio-

cene deposits of this area were largely formed under shallow water conditions.

The lower Miocene of the Chehalis Valley between Montesano and Cosmopolis is predominantly composed of massive sandy shales and shaly sandstones. They contain deeper water marine faunas than at Clallam Bay. The structural conditions occurring in this area have been described in the discussion of the Oligocene. The lower Miocene sandstones and shales outcropping on the banks of Alockaman River in Wahkiakum County have also been referred to and described in the chapter on the Oligocene.

GEOLOGIC STRUCTURE.

Seven anticlinal and synclinal folds have been developed in the sandstones exposed between Pysht and Clallam Bay. One mile east of Pysht River an anticline trends North 15° West. The strata in the eastern limb strike North 10° West and dip 55° to the northwest. Immediately west of this locality and east of the bluff at the mouth of Pysht River, the strike is North 22° East and the dip 75° northwest.

At Pillar Point there are massive sandstones in which a sharp synclinal fold has been developed. The eastern limb at Pillar Point stands nearly vertical and in places is even overturned. About one and one-half miles west of Pillar Point a shallow anticline has been formed with a northeasterly trend. The two limbs are each dipping away from the axis at angles of 15°. From this point westerly to the northwest quarter of Section 31, Township 32 North, Range 13 West, the dip continues westerly but increases to 60°. At this locality there is a closely folded syncline with a northeasterly trend. Both limbs dip 45° to the axis. Fifteen hundred feet west the same strata are folded into an anticline on the township line between ranges 11 and 12. The axis is just one-half mile east of the Clallam Bay coal mine. The strata east of the mine strike North 12° East and dip 15° to the northwest. West of the mine there is a small local fault. Four thousand feet west of the coal mine the sandstones are again folded into a synclinal trough. The

eastern limb strikes North 26° East and dips 15° to the northwest, while the western limb trends North 75° West and dips to the northeast at an angle of 30°. One mile west, the beds swing and strike North 12° East with a dip of 20° to the southeast. Immediately west the same strata are again folded into an anticline and from its axis west to Slip Point the prevailing strike is North 80° West with a northeasterly dip of 60°.

A complete list of the fauna occurring within the lower Miocene is included in the faunal table of the Oligocene. The following species are among the most common within the Arca montereyana Zone: *Arca montereyana* Osmont, *Chione securis* Shumard, *Diplodonta parilis* Conrad, *Pecten propatulus* Conrad, *Pecten fucanus* Arnold, *Tellina arctata* Conrad, *Panope generosa* (Gould), *Phacoides acutilineatus* (Conrad), *Spisula albaria* (Conrad), *Tellina oregonensis* Conrad, *Venericardia quadrata* Dall, *Chione olympidea* Reagan, *Chione clallamensis* Reagan, *Ficus clallamensis* Weaver, *Crepidula praerupta* Conrad, *Fusinus stanfordensis* (Arnold), *Polynices saxea* (Conrad), *Sinum scopulosum* Conrad, *Dentalium conradi* Dall and *Aturia angustata* Conrad.

UPPER MIOCENE

MONTESANO FORMATION.

Geographic Distribution.

The Montesano formation consists of an assemblage of conglomerates and sandstones with subordinate amounts of shale. The deposits attain a maximum thickness of 5,400 feet. They are limited in distribution, being confined to two widely separated areas. The larger is situated in the Grays Harbor region and for the most part north of Chehalis River. The smaller is in southwestern Clallam County in the vicinity of the junction of the Soleduck and Bogachiel rivers. The exact areal limits of the latter are indefinitely defined.

Lithology.

The formation in the Grays Harbor region consists of a thick series of moderately consolidated coarse grained, cross-bedded, brownish gray sandstones which in places become gritty

or even conglomeratic. The conglomeratic belts usually occur in the form of lenses or tongues. The sandstones often are shaly and in the canyon of Wishkah River pass into clay-shales. In the canyons of the two forks of Humptulips River interbedded narrow bands of shale and sandstone are common.

In the Quillayute area shaly sandstones and gritty conglomerates predominate. Shales and sandy shales occur sparingly. The sandstones are commonly cross-bedded. No igneous materials of contemporaneous origin are known to occur.

Stratigraphy.

In the Grays Harbor area the upper Miocene strata have a maximum thickness of 5,400 feet. In the Cape Elizabeth section north of the mouth of Queniult River the sandstones and shales are 3,000 feet in thickness while in southwestern Clallam County similar deposits are 1,500 feet thick. Detailed sections in these areas are included in the discussion of each district. In the Grays Harbor area the basal portion of the section is largely composed of shale or sandy shale, while the upper part consists of sandstones and conglomerates. The basal beds in the Queniult River section are chiefly brown shaly sandstones while the upper beds consist of alternating belts of conglomerates and sandstones containing large fragments of carbonized wood. In the Quillayute area the basal beds are conglomeratic and the upper strata more sandy or shaly.

Fauna

In the Grays Harbor area there is very little variation in the general character of the fauna from the base to the top of the formation. The basal beds were deposited in somewhat deeper water and contain some species which are absent from the shallow water deposits near the top. The deposits outcropping north of the mouth of Queniult River may be slightly younger than those to the south in southern Grays Harbor County. The same may be said for the beds at the junction of Soleduck and Bogachiel rivers in southwestern Clallam County.

The term Yoldia strigata Zone is applied to the faunas occurring within the upper Miocene beds of the Grays Harbor

region. In other words but one faunal horizon is recognized within the Montesano formation. The following species are most common to this zone: *Arca trilineata* Conrad, *Cardium meekianum* Gabb, *Macoma astori* Dall, *Mulinia alta* Weaver, *Mulinea undulifera* (Weaver), *Pecten coosensis* Schumard, *Solen sicarius* Gould, *Yoldia strigata* Dall, *Argobuccinum cammani* Dall, *Chrysodomus imperialis* Dall, *Phalium aequisulcatum* Dall, *Sinum scopulosum* Conrad and *Scutella gabbi* Remond. All the species occurring in this zone are marine types.

The following table includes a list of the species known to occur within the state and the different localities where they have been found:

	LIST OF SPECIES	30	46	52	60	61	68	93	94	96	99	100	101	111
	PELECYPODA													
1	Arca trilineata Conrad		*		*		*							
2	Cardium corbis Martyn						*							
3	Cardium coosensis Dall										*			
4	Cardium meekianum Gabb													*
5	Chione securis Shumard	*		*	*		*				*			*
6	Chione bisculpta Dall						*				*			
7	Chione chehalisensis Weaver						*							
8	Chione montesanoensis Weaver						*							
9	Cryptomya oregonensis Dall						*							
10	Cryptomya washingtonensis Weaver						*							
11	Diplodonta parilis Conrad		*		*	*	*			*				
12	Glycimeris gabbi Dall						*							
13	Leda chehalisensis Weaver													
14	Leda sp.					*								
15	Macoma secta Conrad						*							
16	Macoma nasuta Conrad					*	*							
17	Macoma montesanoensis Weaver					*	*							
18	Macoma calcarea Gmel	*												
19	Macoma piercei Arnold						*							
20	Mactra coalingensis Arnold		*		*		*		*		*			*
21	Modiolus directus Dall						*							
22	Mytillus condoni Dall					*								
23	Mytillus mathewsoni Gabb						*							
24	Mulinea alta (Weaver)					*	*				*			
25	Mulinea undulifera (Weaver)						*							
26	Mulinea landesi (Weaver)					*	*							
27	Marcia oregonensis (Conrad)													
28	Nucula conradi Meek			*			*				*		*	*
29	Panope generosa (Gould)													
30	Phacoides acutilineatus (Conrad)													*
31	Phacoides annulatus (Reeve)			*										
32	Pecten coosensis Shumard													
33	Pecten propatulus Conrad													
34	Solen sicarius Gould		*		*		*							
35	Solen conradi Dall		*											
36	Spisula albaria (Conrad)		*	*	*		*			*				
37	Spisula catilliformis (Conrad)													
38	Semele montesanoensis Weaver						*							
39	Thracia trapezoidea Conrad						*							
40	Thracia oregonensis Dall		*											
41	Tellina kincaidii Weaver						*							
42	Tellina merriami Weaver						*							
43	Tapes stayleyi Gabb		*			*	*							
44	Venericardia castori Dall							*						
45	Yoldia submontereyensis Arnold	*												
46	Yoldia strigata Dall		*		*									*
	GASTEROPODA													
47	Argobuccinum cammani Dall													
48	Argobuccinum coosensis Dall													
49	Bathytoma gabbiana Dall						*							
50	Bathytoma bogachielli Reagan						*							*
51	Buccinium bogachielli Reagan						*							*
52	Calyptraea filosa (Gabb)						*							
53	Chrysodomus imperiallis Dall						*							*
54	Chrysodomus bairdi Dall						*							
55	Chrysodomus giganticus Reagan													*
56	Columbella gauspata Dall		*											
57	Crepidula princeps Conrad		*		*		*							
58	Calliostoma stantoni Arnold													
59	Cymatium pacificum Dall						*							
60	Eulima smithi Reagan													*
61	Eulima washingtonensis Reagan													*
62	Epitonium rugiferum Dall						*							
63	Fusinus montesanoensis Weaver						*							
64	Gyrineum sylviaensis Weaver						*							
65	Gyrineum mediorce var corbiculatum Dall						*							
66	Liomesus sulcatus Dall						*							
67	Nassa andersoni Weaver				*									
68	Nassa arnoldi Anderson	*	*											
69	Neptunia maxfieldi Reagan						*							*
70	Olivella pedroana Conrad				*									*
71	Polynices galianoi Dall						*							
72	Polynices clausa B. & S.	*	*	*	*		*							*
73	Phalium aequisulcatum Dall						*		*					
74	Ranella marshalli Reagan													*
75	Sinum scopulosum Conrad		*											
76	Thais etchegoinensis Arnold		*											
77	Turris coosensis Dall													
78	Turris perversa Gabb													
79	Scutella gabbii Remond						*		*					
80	Dentalium conradi Dall													
81	Teredo sp.													

* From Tertiary Faunal Horizons of Western Washington, University of Washington Publications in Geology, Vol. I, No. 1, pp. 32-33.

UPPER MIOCENE—Continued.

	112	115	117	118	119	120	121	123	124	125	126	132 a	132	140	141	142	144	145	146	147	148	151	152	163	174
1				*	*						*														
2		*									*												*		
3															*	*	*	*							
4																									
5			*								*			*	*		*						*		
6														*		*		*					*		
7																									
8																									
9				*																					
10																									
11														*			*								
12																						*			
13			*	*	*	*			*			*	*						*	*				*	
14																									
15																									
16																									
17																									
18												*	*							*	*				
19																									
20		*						*			*			*	*	*	*	*				*	*		
21																									
22														*		*									
23																									
24										*				*	*	*	*	*							
25																									
26																									
27				*				*																	
28								*			*			*	*		*	*				*			
29																									
30					*	*																			
31																									
32																						*			
33																						*			
34																									
35														*		*									
36	*			*																					
37																									
38																									
39																			*	*					
40																									
41																									
42																									
43																									
44																				*					
45																									
46																									
47										*															
48				*																					
49																									
50																									
51																									
52																									
53																							*		
54																									
55																									
56																									
57			*	*				*	*																
58																									
59																									
60																									
61																									
62																									
63																									
64																									
65																									
66																									
67																									
68				*				*																	
69																									
70		*																							
71										*															
72		*	*											*	*		*	*				*	*		
73				*							*															
74																									
75																									
76																									
77																									
78																									
79																									
80			*	*	*								*							*					
81																									

	LIST OF SPECIES	181	182	185	189	193	194	197	200	201	202	209	210	211	215
	PELECYPODA														
1	Arca trilineata Conrad				*				*						
2	Cardium corbis Martyn						*		*						
3	Cardium coosensis Dall														
4	Cardium meekianum Gabb														
5	Chione securis Shumard				*		*		*						
6	Chione biscalpta Dall						*								
7	Chione chehalisensis Weaver														
8	Chione montesanoensis Weaver														
9	Cryptomya oregonensis Dall														
10	Cryptomya washingtonensis Weaver														
11	Diplodonta parilis Conrad			*			*								
12	Glycimeris gabbi Dall														
13	Leda chehalisensis Weaver														*
14	Leda sp.														
15	Macoma secta Conrad														
16	Macoma nasuta Conrad														
17	Macoma montesanoensis Weaver														
18	Macoma calcarea Gmel														
19	Macoma piercei Arnold						*								
20	Mactra coalingensis Arnold						*								
21	Modiolus directus Dall														
22	Mytilus condoni Dall														
23	Mytillus mathewsoni Gabb							*							
24	Mulinea alta (Weaver)	*					*								
25	Mulinea undulifera (Weaver)														
26	Mulinea landesi (Weaver)														
27	Marcia oregonensis (Conrad)														
28	Nucula conradi Meek								*				*		
29	Panope generosa (Gould)				*			*							
30	Phacoides acutilineatus (Conrad)														
31	Phacoides annulatus (Reeve)														
32	Pecten coosensis Shumard									*					
33	Pecten propatulus Conrad	*				*									
34	Solen sicarius Gould														
35	Solen conradi Dall				*				*						
36	Spisula albaria (Conrad)	*			*		*								
37	Spisula catilliformis (Conrad)				*										
38	Semele montesanoensis Weaver														
39	Thracia trapezoidea Conrad													*	*
40	Thracia oregonensis Dall														
41	Tellina kincaidii Weaver														
42	Tellina merriami Weaver														
43	Tapes staleyi Gabb														
44	Venericardia castori Dall											*			*
45	Yoldia submontereyensis Arnold										*				
46	Yoldia strigata Dall				*										
	GASTEROPODA														
47	Argobuccinum cammani Dall											*	*	*	
48	Argobuccinum coosensis Dall														
49	Bathytoma gabbiana Dall														
50	Bathytoma bogachielli Reagan						*								
51	Buccinium bogachielli Reagan						*								
52	Calyptraea filosa (Gabb)														
53	Chrysodomus imperialis Dall						*								
54	Chrysodomus bairdi Dall														
55	Chrysodomus giganticus Reagan														
56	Columbella gauspata Dall														
57	Crepidula princeps Conrad				*		*								
58	Calliostoma stantoni Arnold	*													
59	Cymatium pacificum Dall														
60	Eulima smithi Reagan														
61	Eulima washingtonensis Reagan														
62	Epitonium rugiferum Dall														
63	Fusinus montesanoensis Weaver														
64	Gyrineum sylviaensis Weaver														
65	Gyrineum mediorce var corbiculatum Dall						*								
66	Liomesus sulcatus Dall														
67	Nassa andersoni Weaver														
68	Nassa arnoldi Anderson														
69	Neptunia maxfieldi Reagan														
70	Olivella pedroana Conrad														
71	Polynices galianoi Dall						*								
72	Polynices clausa B. & S.				*		*		*						
73	Phalium aequisulcatum Dall						*								
74	Ranella marshalli Reagan														
75	Sinum scopulosum Conrad				*										
76	Thais etchegoinensis Arnold														
77	Turris coosensis Dall														
78	Turris perversa Gabb	*													
79	Scutella gabbii Remond														
80	Dentalium conradi Dall														*
81	Teredo sp.														

Geologic and Structural Map at Mouth of Queniult River.

GRAYS HARBOR AREA.

Geographic Distribution. The upper Miocene formation in the Grays Harbor region lies almost entirely north of Chehalis River and within the drainage basin of Satsop, Wynoochee, Wishkah, Hoquiam and Humptulips rivers. From the Humptulips westward to the ocean all of the bedrock formations are covered with Pleistocene fluviatile deposits consisting of sands, gravels, and clays. The older Montesano formation, however, reappears on the Queniult Indian Reservation north of Point Grenville and in the vicinity of Cape Elizabeth.

The south contact with the Oligocene is designated upon Plate III. Its position is only approximate and has been determined partly on a palaeontological and partly upon a lithologic basis. The eastern contact with the older Tejon basalts is very indefinite. The bedrock formations are in most places heavily covered with deposits of glacial drift. Occasionally small exposures of basalt or sandstone occur and it is by tracing the approximate lines between these that the contact on the map has been determined.

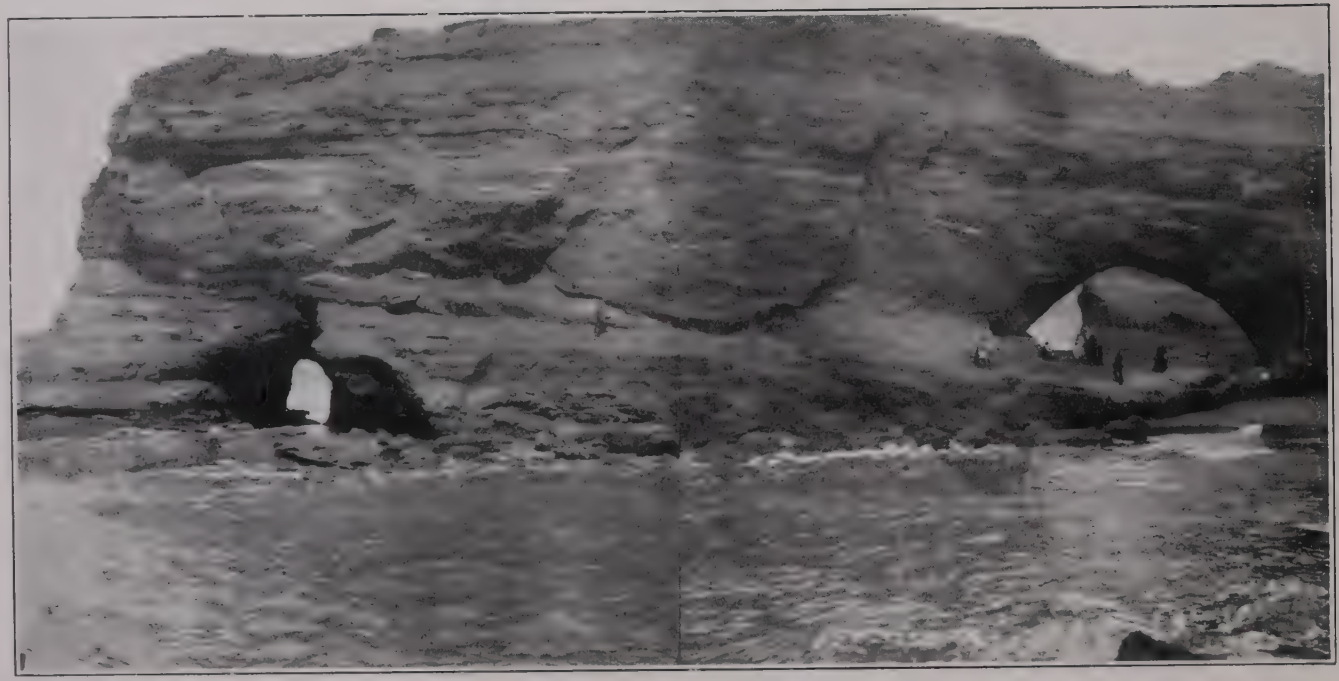
The north contact with the Tejon basalt has been definitely determined at certain points as in the canyons of Wynoochee, Wishkah, and Humptulips rivers. Between these points its approximate position has been determined and located by an examination of the exposures in the smaller creeks. The contact presumably extends northwesterly and crosses Queniult River near the basalt exposures in the Burnt Hills in Section 12, Township 22 North, Range 11 West. The western contact has been drawn only approximately and west of it there is no means of determining what the underlying formation may be.

Character of Outcrops. The surface topography of the area just outlined is rolling and heavily veneered over with rusty colored gravels and sands. This plain has been dissected by the Satsop, Wynoochee, Wishkah and Humptulips rivers. Along the banks of these streams the bed rock is in many places exposed. The smaller creeks sometimes cut into bed rock but more often only into the fluviatile sands and gravels. The

original pre-Pleistocene surface topography was undulating. The deeper depressions were filled with thicker accumulations of Pleistocene gravels and sands. Where the present rivers cut across these areas, as a rule, bed rock has not as yet been intersected. Where the rivers have cut down into the older formations, high bluffs are sometimes present. Occasionally the rivers flow in deep gorges as in the upper part of the Wynoochee Valley. This is especially true farther north in the basaltic areas.

Steeper bluffs are situated along the south side of Chehalis River and excellent exposures of the formation may be seen in the railway cuts and excavations. In Township 18, North, Ranges 7 and 6 West, very little overburden of gravel and sand is present. The typical coarse sandstones of the Montesano formations are well exhibited. A large part of the area has been logged off and numerous rock cuts have been made. This is also true where the smaller streams emptying into Satsop River have cut down into bed rock. Almost continuous outcrops may be seen in the logging railroad cuts along Sylvia Creek north of Montesano. These exposures rapidly pass into soil after having been exposed for some time. On the west and middle branches of Wishkah River, good outcrops occur in the banks of the streams from the basalt contact on the north southward to Grand Forks. Often these appear only a few feet above the bed of the streams and sometimes are separated by gravel areas so that the Montesano formation does not appear at all. Similar exposures occur on Humptulips River from the basalt contact in Section 35, Township 21 North, Range 9 West, westerly to the junction with the west branch of the same river. From that point to Humptulips City the area through which the Humptulips flows is flat and gravel-covered and no bedrock bluffs occur. One mile south of Humptulips City rock exposures reappear but from that point to its mouth they are deeply covered with gravels and sands of Pleistocene age.

Beginning at a point three miles east of Aberdeen the Montesano formation outcrops almost continuously to Hoquiam and



Upper Miocene Formation as Exposed at Cape Elizabeth, Grays Harbor County.

beyond for some distance. Both the Wishkah and Hoquiam rivers have cut through it. About three miles north of this belt the country merges into an undulating flat-topped plain heavily covered with gravel. Very few bedrock exposures occur in this region. On the south side of Chehalis River from Cospomolis to West Aberdeen and for three miles south, the massive sandstones of the Montesano formation are conspicuous. Farther south the country is heavily timbered and covered with gravel and sand.

Lithology. The upper Miocene deposits of Washington are largely composed of materials deposited under conditions ranging from shallow water to that of moderate depth. Coarse grained brownish gray sandstones prevail. Often these become gritty and locally pass into a fine conglomerate. Cross-bedding is characteristic of the series. The shales, when present, are generally bedded and often contain intercalated layers of sandstone. Occasionally hard nodules are developed in the shales. The shales are fine-grained and of a bluish gray color. Typical examples of the sandstones may be seen in the street cuts of Hoquiam and Aberdeen, on Sylvia Creek back of Montesano and on Vance Creek between Satsop and Elma. The shales which are most prominent in the lower portion of the series are best developed on the upper courses of Wishkah River. They also occur on the Humptulips River above the junction of the west and east forks, on the latter.

Geologic Structure. The prevailing structure which the strata of the Montesano formation assume in this area consists, in common with that south of Grays Harbor, of a series of northwest to southeast anticlinal and synclinal folds.

Detailed traverses were run along the Humptulips, Wishkah and Wynoochee rivers. The strata were measured and the strikes and dips recorded. The positions of the anticlinal and synclinal axes have been designated upon Plate III.

At Humptulips City in Section 7, Township 20 North, Range 10 West, an anticline crosses the river, trending North 60° West. On the north limb the shales are dipping at angles

ranging from 60° to 78° to the northeast. On the south limb the dip is 35° to the southwest. How far this anticline extends to the northwest or southeast cannot at present be determined as all bedrock exposures are obscured by the overburden of Pleistocene gravels and sands.

In Sections 1, 2, and 3 of the same township and range an anticline trends nearly parallel to the river for two miles and bears off to the southeast. Observations show it to cut from one bend of the river to another. Rock exposures are almost continuous and observations taken on the north limb of the anticline show it to dip from 42° to 82° to the north and northeast. On the south limb the dip varies from 35° to 85° to the southeast. On both flanks the dip varies from point to point along the trend of the anticline. About half way between the two anticlines just described a synclinal trough is assumed to exist. No exposures are present in this region and its exact position and extent cannot be determined.

In Section 20, Township 20 North, Range 8 West an anticline crosses Wishkah River, trending North 70° West. The north flank is pitching to the northeast at an angle ranging from 30° to 60°. The south limb dips 54° to the southwest towards the axis of a parallel syncline passing through the extreme northeast corner of Section 31, same township and range. South from this synclinal axis for a distance of three miles, the strata are dipping to the northeast at angles ranging from 17° to 14°. In Section 12, Township 19 North, Range 9 West an anticline again crosses Wishkah River trending in the same direction. South from it the gravels and sands become thicker and deeper and bed rock exposures in the river banks are not so common.

The southeastern extension of the last anticline described, crosses Wynoochee River in Section 28, Township 19 North, Range 8 West. The intervening area between the Wynoochee and Wishkah rivers is largely devoid of bed rock outcrops so that the underlying structure cannot be definitely determined. To the east of Wynoochee River the outwash from the Puget

Sound glacial field covers the region so thickly that no attempt has been made to work out definite structure. In Township 18 North, Range 7 West, exposures are fairly abundant and the strata are dipping at low angles ranging from 5° to 15° to the north. On the east fork of Satsop River in Section 5, Township 18 North, Range 5 West, the strike is North 75° West and the dip 20° southwest. It is possible that a shallow synclinal trough trends northwest to southeast between these two localities.

Stratigraphy. The following stratigraphic section has been measured from exposures occurring along the middle fork of Wishkah river. The base of this section lies in Section 14, Township 19 North, Range 9 West.

WISHKAH RIVER TRAVERSE.

	Feet
Bluish gray shale	500
Gray shaly sandstone (Fossil Loc. 117-119)	350
Brown gray sandstone—concretionary	200
Bluish gray, shaly sandstone	550
Massive gray sandstone (Fossil Loc. 121)	100
Gray shaly sandstone	450
Blue gray laminated sandy shale	100
Gray sandy shale	50
Sandstone with nodules	60
Sandstone (Fossil Loc. 123)	200
Gray sandstone	1300
Gray sandy shale (Fossil Loc. 125)	300
Sandstone	900
Conglomerate	400
Base of section at station 269.	
Total	5460

To the northwest in the lower valley of Queniult River the upper Miocene strata have been folded into a shallow synclinal trough which pitches inland in a northeasterly direction. Minor folds exist on the flanks of this syncline. In Section 12, Township 21 North, Range 13 West, a small local syncline and anticline have been formed whose axes trend northeast and southwest. In Section 34, Township 22 North, Range 13 West, a small fold in the nature of a monocline passes from the shore south of Cape Elizabeth in a northeasterly direction. A fault exists trending from a point on the coast about one mile

north of the Cape southeasterly to the big bend in Queniult River in the southeast quarter of Section 6, Township 21 North, Range 12 West. A block of the Hoh formation lies on the eastern side of the fault plane in contact with the upper Miocene strata. East of the Hoh fault block the Miocene gravels and sandstones again appear. The eastern portion of the Queniult Indian reservation affords no opportunities for determining the structural conditions of the upper Miocene strata.

Near the mouth of Queniult River the upper Miocene strata are well exposed. From a point about one mile north of Cape Elizabeth south to the mouth of the river a detailed stratigraphic section has been measured. The top of this section is located along the shore north of the mouth of the river and the base at the fault contact north of Cape Elizabeth. (Plates XXVI, XXVII, XXVIII and XXIX.)

DETAILED CROSS SECTION, UPPER MIOCENE, AT CAPE ELIZABETH.

Top	*Feet*
Shaly sandstone	2
Medium grained conglomerate	25
Sandy shale	2
Conglomerate	18
Shaly sandstone	7
Conglomerate	28
Sandstone with lenses of conglomerate	14
Nodular sandstone	11
Medium grained conglomerate	5
Hard sandstone	3
Conglomerate with large pebbles	18
Shale	3
Concretionary shale	30
Medium grained conglomerate	12
Shale	30
Coarse conglomerate	8
Sandy shale	15
Conglomerate	10
Sandy shale	15
Loosely consolidated conglomerate	20
Sandy shale	15
Medium grained conglomerate	40
Shaly sandstone with nodules	12
Fine conglomerate	3
Sandy shale	9
Conglomerate	14
Sandstone	3
Conglomerate	2
Sandy shale and clay nodules	3
Conglomerate with a few angular pebbles	35
Sandy shale	10

Top	*Feet*
Medium grained conglomerate	2
Shaly sandstone	2
Conglomerate with fine layers of sandstone	13
Shaly sandstone	14
Conglomerate	10
Shaly Sandstone	6
Fine conglomerate	4
Pebbly sandstone	10
Laminated sandstone	14
Fine conglomerate	10
Soft shaly sandstone	12
Conglomerates	23
Shaly sandstone	12
Medium grained conglomerate containing hard clay nodules	11
Massive shaly sandstone	26
Intercalated sandstone and conglomerate	15
Shale	16
Sandstone	6
Massive sandy shale	12
Medium grained conglomerate	11
Massive medium grained sandstone containing hard nodules	10
Coarse conglomerate	10
Nodular shale	4
Massive medium grained sandy shale occurring at the keyhole	41
Sandy shale	2
Medium grained conglomerate	2
Medium grained shaly sandstone	7
Shaly sandstone	4
Fine grained shaly sandstone	11
Coarse grained sandstone	15
Sandy shale	3
Fine conglomerate	2
Shaly sandstone	2
Shaly sandstone, containing pebbles	6
Conglomerate	15
Sandstone	3
Fine grained conglomerate	6
Shale	1
Sandstone with pebbles	3
Shaly sandstone	1
Sandstone and conglomerate	9
Sandstone	3
Conglomerate	3
Shale	2
Sandy conglomerate	25
Conglomerate	3
Conglomerate and sandstone	12
Conglomerate	9
Sandstone	12
Conglomerate	1
Sandstone	1
Shaly sandstones	12
Sandstone	5
Sandy shale with hard, nodular layers	10
Banded sandy shale	15
Sandy shale	15
Base of section.	
Total	936

QUILLAYUTE AREA.

Geographic Distribution. Upper Miocene strata outcrop at several localities in the vicinity of the junction of the Bogachiel and Soleduck rivers in southwestern Clallam County in the central portion of Township 28 North, Range 14 West. The exact contact boundaries can be only approximately determined as the outcrops are few in number. The greater part of the country is covered with soil and undergrowth. It is probable that only one area exists and its approximate contacts have been indicated by broken lines on Map A, Plate IV.

Character of Outcrops. The surface outcrops are confined chiefly to low bluffs on the banks of Bogachiel and Soleduck rivers. On the Soleduck River in Section 16, Township 28 North, Range 14 West, outcrops of sandy shale and shaly sandstone occur which in places are fossiliferous. These exposures are located on the left bank of the stream in cliffs about twelve feet in height and extend for a distance of 500 feet. They are covered unconformably with river gravels and boulders. A number of similar exposures outcrop on Bogachiel River in Sections 27, 28 and 29, same township and range. They occur in the form of low bluffs along the banks of the river and contain marine fossil molluscan remains.

Lithology. The upper Miocene strata in this region are entirely of sedimentary origin and were deposited in a marine embayment. They consist of sandstones, shaly sandstones and sandy shales. The sandstone is very compact, medium grained and when unweathered of light gray color. It is hard and resistant to weathering. The shales are of a brownish gray color, somewhat massive and weather in angular fragments. They are not hard, but rather tough. Occasional gravelly or gritty layers or lenses are interbedded. The thickness has not been exactly determined but approximates at least 1,500 feet.

The strata assume very low dips so that wherever exposures may be seen along the river banks not over ten or twelve feet of a section can be measured at any one place. The materials do not vary in the section at any particular locality, consequently no detailed sections of the formation have been made.

Geologic Structure. The upper Miocene as represented in this region rests unconformably upon the Hoh formation. Observations taken upon outcrops along Bogachiel River show the prevailing strike to be approximately North 70° West and the dip 10° to 15° to the northeast. Observations taken on Soleduck River indicate a similar strike with a very low dip to the south. Apparently these strata have been folded so as to constitute a shallow syncline with an axis trending a little north of west. The area now exposed presumably represents only the residual of a formerly much more extensive deposit. It is possible that small patches may exist farther to the north which so far have escaped detection. The country is low and flat and outcrops are few.

These sediments were deposited in a basin or inlet from the ocean which was developed at some time after the middle Miocene mountain making movements had taken place. The seas apparently were not deep at any time so only shallow water species of molluscs are found. The climate as interpreted by the types of life present was colder than during the lower Miocene. It was probably very similar to that of the present time.

Fauna. The fauna consists of 20 species of Pelecypods and Gasterpods. Nearly all of these were collected from locality numbers 111, 112, 113, 114 and 115. The largest collection came from the bluffs on the south side of Bogachiel River in Section 28, Township 28 North, Range 14 West, where a small creek enters the river from the south. Along this bluff is the old abandoned channel of Maxwell Creek. The exposures for some distance up Maxfield Creek are not a part of the upper Miocene but rather of the Hoh formation. The following fauna were collected from this locality.

PELECYPODA

Cardium meekianum Gabb
Chione securis Shum
Phacoides acutilineatus Conrad
Yoldia strigata Dall
Nucula c. f. *conradi* Meek
Spisula albaria Conrad
Mactra coalingensis Arnold
Arca trilineata Conrad
Spisula catiliformis Conrad

GASTEROPODA

Buccinium bogachielli Reagan
Chrysodomus giganticus Reagan
Chrysodomus imperialis Dall
Eulima washingtoniana Reagan
Eulima smithi Reagan
Natica clausa B and S
Ranella marshalli Reagan
Polynices lewisii
Olivella pedroana Conrad
Polynices galianoi Dall

FIGURE A.—Upper Miocene Sandstones Looking South From Cape Elizabeth Toward Queniult River.

FIGURE B.—Upper Miocene Shale Looking North From Point Grenville Towards Queniult River.

Of these the most common species are *Spisula albaria*, *Spisula catiliformis*, *Chrysodomus imperalis*, *Chione securis*, *Chione meekianum* and *Yoldia strigata*.

SNOQUALMIE GRANODIORITE.

Outcrops of granodiorite are exposed at the surface at many points in the western foothills of the Cascades. They were in part formed at or near the close of the Jurassic period and in part during the later portion of the Miocene epoch. The former have been described as the Index granodiorites. The latter are exposed in eastern King County in the valley of Snoqualmie River. The hills between the north and south forks of Snoqualmie River are largely composed of granodiorites which are intrusive into a series of quartzites and schists of presumable early Mesozoic age. Similar rocks exist to the south of the south fork of Snoqualmie River as far as the crest of the divide with Cedar River. Along the wall of Cedar River Valley the granodiorites are capped by flows of andesite and deposits of tuff of enormous thickness. Exposures of granodiorite occur almost continuously from North Bend easterly to the crest of the Cascade Mountains. Near the headwaters of Snoqualmie and Cedar rivers the granodiorites have been studied and mapped by the U. S. Geological Survey and are designated in the Snoqualmie Folio as the Snoqualmie granodiorite.* They are believed to be of late Miocene age. On the basis of studies made in that region and on the fact that areal exposures of the same formation can be traced continuously from the border of the Snoqualmie Folio westerly to the junction of the south and middle forks of Snoqualmie River, the granodiorites of this region are regarded as of upper Miocene age and a part of the Snoqualmie granodiorite.

A field examination of the granodiorite shows a considerable variation in texture and mineral composition. Basic secretions of badly altered hornblende and biotite are common. Aplitic intrusions are characteristic near the contact of the bathylith

* Smith, G. O. and Calkins, F. C., Snoqualmie Folio, U. S. Geological Survey, No. 139. 1906.

with the overlying schists and quartzites. Away from the contact the rock possesses a somewhat uniform character. It is medium grained and composed of biotite and hornblende with plagioclase and minor amounts of quartz. Under the microscope the rock is seen to be largely composed of plagioclase of the oligoclase variety and biotite. Orthoclase is present in subordinate amounts. Quartz is clear and glassy and forms on the average about 10% of the total content of the rock. Green hornblende is fairly abundant but subordinate in amount to biotite. Small prisms of apatite and occasional crystals of titanite are often present. Except when unduly exposed to weathering the rock as a whole is comparatively fresh.

ENUMCLAW VOLCANIC SERIES.

Geographic Distribution.

In eastern Snohomish, King and Pierce counties there are extensive accumulations of lava and tuff resting unconformably upon older quartzites, schists and granodiorites, as well as the Eocene and Oligocene sedimentary formations of the eastern portion of the Puget Sound Basin. They account in part for the somewhat steep escarpments along the western foothills of the Cascade Mountains. In King County the estuarine Eocene deposits outcrop in nearly all the river and creek canyons as far east as the western escarpment of the Cascades where they disappear beneath the lavas and tuffs. This contact extends from Fall City southerly along Raging River to Barneston and thence along the Northern Pacific Railway to Enumclaw and Carbon River. Residual patches of lava occur in many places to the west of the contact. The northern boundary of this volcanic area extends from the town of Snoqualmie southeasterly along the east wall of Snoqualmie Valley to the foot of Rattlesnake Ledge near the town of Cedar Falls and thence up the northern side of Cedar River Valley. Similar lavas are exposed on the south side of Skykomish Valley in Snohomish County as far as the eastern margin of the Puget Sound Basin. In southern Pierce and in Lewis counties the lavas are exposed to the

southwest and are sometimes difficult to separate from the Eocene volcanic flows especially in those areas where glacial deposits are extensive.

Lithology.

Rock exposures are often exhibited in the rugged and steep cliffs along the canyons of the rivers and creeks flowing westerly through the Cascades. The basal portion of the formation may be seen in the small creeks one mile south of North Bend. Granodiorites and quartzites form the outcrops up to elevations of approximately 800 feet. Above the granodiorites are flows of badly altered basic andesite. The lower flows are somewhat porphyritic although the crystals are usually small. A microscopic examination of the fresher material shows the presence of basic labradorite together with augite and minor amounts of hornblende. The higher flows exposed in the ridge occur on the top of Rattlesnake Ledge and are pitching to the southwest at an angle of 30°. They range in character from a vesicular rock to a massive agglomerate. The several phases are interbedded as bands of varying thickness. Excellent outcrops of the lavas may be observed in the canyon of Cedar River below Cedar Lake. They are also pitching to the southwest and Cedar River has cut down diagonally across the strike. At the site of the new Cedar River dam excavations have been made and the detailed character of the rocks may be studied. The rocks as exposed consist of fine grained andesites intercalated with distinctly bedded fine grained bluish gray volcanic ash. The ash bands vary in coarseness of grain and often contain small pieces of pumice. Thick bands of tuff are present which contain angular fragments of pumice, vesicular lava, fine grained, dense glassy andesite together with fragments of carbonized wood. In the bedded tuffs or clays fossil leaves are in places abundant. In the vicinity of Enumclaw the lavas are in the nature of acidic basalts. They occur intercalated with light colored tuffs which are resting nearly horizontal and possess a thickness of at least 1,000 feet.

Detailed examinations were not undertaken on the western slopes of the Cascades but from such observations as were made along the canyons of White and Green rivers the lavas and tuffs occur as gentle folds all of which are trending northwest and southeast. Along the western margin of the lava escarpment there is some evidence of complex and repeated faulting parallel to the contact. The differential resistance to erosion of the lavas as compared with the softer Eocene sedimentaries is in part responsible for the abrupt and somewhat linear termination of the western border of the foothills of the Cascades.

On the south side of the ridge extending from North Bend to Newcastle numerous intrusive dikes occur cutting the Eocene sedimentaries. This is especially true between Raging River and Issaquah Creek. It is possible that these dikes may have been feeders to lava flows in that region which have since been removed by erosion. The area is thickly covered with deposits of glacial drift and it may be that residuals of lava are present which have not as yet been observed because of the drift.

Correlation.

The contact between the lava series and the underlying granodiorites in Snoqualmie Valley is one of unconformity rather than intrusion. The same condition exists with respect to the Eocene sedimentaries and the lavas at Durham, Kanaskat and Enumclaw. The lava series as exposed at the above localities when traced easterly, directly connects with the Keechelus volcanic series, as exposed along the Cascade divide in the Snoqualmie Folio. The lavas as mapped in this folio have been described by Dr. G. O. Smith as of upper Miocene age and were regarded by him as older than the Snoqualmie granodiorite. The granodiorite is described as being intrusive into at least a part of the Keechelus formation.

The lavas referred to in this report as occurring along the western border of the Cascade Mountains are described as the Enumclaw volcanic series. It is possible that they may be in part the equivalent of the Keechelus formation. The granodior-

ites south of North Bend are not intrusive into the Enumclaw volcanics but the lavas as exposed there may be the equivalent of the upper portion of the Keechelus formation as exposed near the summit of the Cascades. There does not seem to be any evidence at present to warrant a direct correlation of the Enumclaw volcanic series with the Keechelus formation although they are probably in part equivalent.

CHAPTER VI.

PLEISTOCENE FORMATIONS.

GENERAL STATEMENT.

Deposits of Pleistocene age are well developed in western Washington. They consist of glacial drift, fossiliferous marine sands, clays and gravels, old stream gravels and sands, recent stream alluvial deposits, and sand-bar and tidal flat deposits. For purposes of mapping, as well as discussion, these deposits have been divided into two broad groups, namely, glacial morainic deposits and terrace deposits.

GLACIAL DEPOSITS.

GENERAL STATEMENT.

In this report no attempt has been made to study in detail the glacial deposits of western Washington except in a general way to note their distribution. Careful attention has been given to the glacial question by Bailey Willis* and J. H. Bretz**. The generalization here set forth is largely a summary of their work.

On the geologic map accompanying this report glacial deposits have been mapped only when it was impossible to determine the probable nature of the underlying formations. (Plates II, III and IV.) The contact lines as drawn to limit the boundaries of the drift in reality represent the boundaries between those areas which are covered with drift where the underlying bedrock is unknown and those drift covered areas where the underlying formations are known.

GEOGRAPHIC DISTRIBUTION.

Deposits of glacial origin occupy a large part of the Puget Sound Basin, the north and south borders of the Olympic Peninsula and the north portion of the Grays Harbor region. Out-

* Tacoma Folio No. 54, U. S. Geological Survey 1896.
** Bulletin No. 8, Washington Geological Survey, 1913.

wash gravels which are to be regarded as of glacial origin extend into Grays Harbor, Thurston and Lewis counties. Local morainic deposits may be found in the San Juan Islands and in the foothills of the Cascade Mountains. Deposits formed by alpine glaciation are common in the higher elevations of both the Cascade and Olympic mountains. Small alpine glaciers are in existence today in both of these mountain ranges at the headwaters of the larger stream valleys and on the slopes of the higher mountain peaks.

CHARACTER OF PLEISTOCENE GLACIATION IN WESTERN WASHINGTON.

Early in the Pleistocene the Cascade Mountains had been elevated into their present position. The Juan de Fuca trough had been brought to sea level or possibly below. A series of deep channels having a north-south direction, had been developed in the Puget Sound downfold. Possibly these stream valleys may have been depressed sufficiently to allow the marine waters to enter, although we have no direct evidence that such was the case. The climate had been gradually growing colder during the Tertiary. Precipitation probably increased. Abnormal precipitation in the form of snow allowed great snow fields to accumulate both in the Cascade Mountains and in British Columbia. These ice streams increased in size and flowed down the early Pleistocene stream valleys and coalesced in the great Puget Sound-Strait of Georgia plain into which they emptied. Ultimately this great plain or basin was filled so as to constitute one great field of ice. Later the ice retreated and left behind various types of glacial deposits brought down from the mountains by the glaciers. These deposits have been designated as the Admiralty till. The time interval during which the Admiralty glacier occupied the Sound region has been termed the Admiralty epoch.

At the close of the Admiralty Epoch the great ice sheet began to retreat. It finally disappeared leaving the entire Puget Sound region covered with detritus. During this time the region was being elevated, perhaps to 1,000 feet. Stream erosion became active and great valleys were cut down into the deposits

FIGURE A.—Upper Miocene Formations as Exposed Along Beach North of Cape Elizabeth.

FIGURE B.—Point Grenville, Showing Eocene Basalts on Beach at Low Tide.

of the Admiralty glaciation. The time interval involved in the retreat of the ice, in uplift and extensive erosion and aggradation is known as the Puyallup interglacial epoch. All of the main stream channels formed during this time are thought to have had a predominant north-south trend.

Towards the close of the Puyallup Epoch conditions again allowed the development of great ice streams in the valleys of British Columbia and the Cascade Mountains of Washington. They advanced and the Puget Sound basin was again filled with ice. The margins of this great ice field even crowded up into the stream valleys issuing from the Olympic Mountains. To the south the margin of the ice advanced to the already subdued core of the Black Hills upwarp. Two great lobes were developed. One of these passed to the south and east of the Black Hills and the other swung around to the west through a low gap extending towards Matlock. Beyond the limits of the terminal moraine at the front margin of the glacier there are spread out great outwash gravel plains. These extend from Mason County westerly to Grays Harbor and from the eastern lobe over the plains of Thurston County into northern Lewis County at Centralia. During this maximum advance of the ice the front margin of the glacier oscillated back and forth so as locally to allow the morainic material to over-ride the outwash gravels.

This field of ice is considered to have extended as a solid mass from the Cascades to the Olympics. As it began to retreat by the melting away of the front margin, a great pond of water accumulated which could not escape to the north because of the ice wall, nor to the south because of the rock and morainic barriers. In places streams were able to spill over the front retaining wall and cut out drainage channels, but not sufficiently to drain the lake. As the ice field gradually retreated to the north the lake became larger. It was bordered on the west by the Olympics, on the east by the Cascades, on the north by the ice front and on the south by the rock ridge. As the lake increased in size, streams from the Olympics and Cascades began

to drain into it. Great deltas were developed on its margin. These gradually extended out into the lake. The sediments laid down were characterized by cross-bedding. Ultimately the ice retreated sufficiently to the north to allow the waters of the lake to drain to the ocean through the Strait of Juan de Fuca. The Strait of Juan de Fuca had itself been filled with ice during the maximum extent of glaciation. The present topographic features of the Sound owe their origin largely to the conditions which prevailed during Pleistocene glaciation. The time interval during which this last ice field advanced and retreated has been termed the Vashon glacial epoch.

It is thought that the Puget Sound basin had been lowered from its former elevated position to nearly its present elevation during the time of maximum Vashon glaciation. After the ice had entirely retreated the region is believed to have been submerged 250 feet more. Later it was again re-elevated to approximately its present position. The evidence for this is the occurence of elevated beaches containing marine shells.

The latest diastrophic movement consisted of a slight elevation of perhaps twenty feet above sea level so as to produce rock cut terraces and deposits of marine molluscan remains as may be seen at the entrance to the Bremerton Navy Yard and at Alki Point in Seattle. These marine deposits will be discussed under the marine phase of Terrace Deposits which is to follow.

TERRACE DEPOSITS.

GENERAL STATEMENT.

Under the general term, terrace deposits, for purposes of convenience in mapping, are included all deposits of Pleistocene age excepting those of definite glacial origin. More important among these are old fluviatile deposits of Pleistocene age, recent alluvial deposits, products of rock decay which are still in place, sand dunes, marine beach deposits, and tidal flat muds. These will be described in the order just referred to.

FLUVIATILE DEPOSITS.

Under fluviatile deposits are included the sands, gravels and clays deposited by Pleistocene river channels at a time when the surface of the western portion of the state was much lower than at the present time. These deposits vary much in thickness as well as in character. They form extensive accumulations along the west and south margins of the Olympic peninsula, along the shores of Willapa and Shoalwater bays, in the Cowlitz Basin and in the counties bordering Columbia River. They record the shifting and meandering of numerous streams. After their deposition the entire western portion of Washington appears to have been uplifted and the present streams have carved their channels down through this earlier river wash and in places have cut into the underlying older Tertiary bedrock formations.

Along the western slope of the Olympic Mountins there is an uplifted plain extending from Cape Flattery southward to Grays Harbor. This belt averages twenty miles in width and extends up into the western foothills of the Olympic Mountains. On the west it is terminated by the ocean. Lithologically these deposits consist of gravels, sands, and clays. The gravels are composed of pebbles, largely of quartzite origin and ranging from one inch to over one foot in diameter. They generally show slight evidences of stratification. The sands, which are very slightly consolidated, are commonly characterized by cross-bedding and often pass into coarse grits. The clays are commonly massive and of a bluish gray color. The sands are nearly always stained a yellowish red. Typical examples of these deposits may be seen in the cliffs along the ocean shore line, as well as in the banks along the river channels which empty into the ocean. This uplifted plain at one time extended much farther out to sea than at present and is rapidly being cut into by the ocean waves. The gravel deposits sometimes constitute the ocean bluffs down to and below the level of the beach. In other places the basal contact gradually rises above sea level, as the older bedrock formations come into view. The probabilities are that if all of these deposits should be removed

from this particular region under consideration the pre-Pleistocene surface would exist largely below sea level, leaving numerous rock islands off a shore approximately twenty miles east of the present shore line.

Nearly all of the area involved in the Queniult Indian Reservation and that part of Grays Harbor County west of Humptulips River south of Grays Harbor is composed of these materials. Their base is almost entirely below sea level. These same deposits extend easterly from Grays Harbor and veneer over much of the area in the valleys of Wishkah and Wynoochee rivers. In eastern Grays Harbor and Mason counties they are replaced by gravels and sands of direct glacial origin.

Along the shores of Willapa and Shoalwater bays there are cliffs ranging from 50 to 300 feet in elevation above sea level, composed of soft incoherent yellowish brown sands, gravels, and clays. They are especially prominent in the vicinity of Bay Center, Nemah River and Long Island. Similar deposits veneer over a large part of the wooded country in the low areas of Pacific County. On the north bank of Columbia River at the town of Ilwaco, horizontal beds of these deposits may be seen resting unconformably upon the upturned strata of the lower Miocene. Deposits of the same nature rest upon the Eocene lavas and sandstones in the vicinity of Grays Bay and eastward into Wahkiakum County.

In the Cowlitz Basin, these deposits occur as terraces along the streams entering Cowlitz River. They generally assume a horizontal position. Excellent exposures may be seen immediately south of Castle Rock and along the river and railway cuts northward from that point towards Olequa. Wherever the pre-Pleistocene topography was composed largely of basaltic rocks, angular fragments of such material enter into the composition of the Pleistocene deposits. In the railroad cuts between Castle Rock and Little Falls, numerous instances of this kind occur. These have been described as Pleistocene lava flows.* Upon examination, however, this lava is found to occur in irregular shaped blocks mixed with sands and river

* Proceedings American Philosophical Society, Volume LII, No. 212, 1913.

gravels, showing conclusively that they have been derived from old rock masses of Eocene age which have been rapidly torn down by weathering and incorporated within the Pleistocene detrital material.

On the slopes of the higher ridges south of Chehalis River, thin layers of yellowish brown sandy clays are found spread over the surface. These are in part of the same origin as the deposits previously mentioned and in part due to extensive long continued rock decay. In these instances the products of rock decay do not appear to have been transported any considerable distance from their original place of formation.

In those areas where basaltic lavas constitute the larger part of the bedrock formations this type of weathering is especially prevalent and attains a thickness of over 50 feet. Wherever suitable exposures have been made, it is found to grade downwards into partially decayed basalt and ultimately into the fresh material. These Pleistocene fluvial deposits which have been uplifted above sea level assume a thickness of at least 400 feet and grade from that downwards to a thin veneer.

MARINE PLEISTOCENE DEPOSITS.

Around the shores of Puget Sound there are numerous raised beaches elevated from fifteen to eighteen feet above sea level. Scattered over the surface of these beaches and embedded in the sands and gravels composing them are the fossil remains of marine molluscs consisting of species very similar to those now living. The Pleistocene marine gravels and sands rest unconformably upon the upturned edges of the older pre-Pleistocene bedrock formations. In places they also lie upon the glacial deposits formed during the last glacial retreat.

Excellent examples of these deposits may be seen around the shores of Restoration Point and on the south side of the entrance to the Bremerton Navy Yard. Similar occurrences exist at Alki Point in Seattle and in places as far north as the San Juan Islands. Deposits which are probably to be correlated with these occur on Vancouver Island. Those on the Saanich Peninsula north of Victoria have been described as the Saanich formation.

RECENT ALLUVIAL DEPOSITS.

In the river valleys unconformably overlying all of the older pre-glacial as well as glacial formations there are deposits of alluvial material which are being deposited at the present time by streams during stages of high water. These materials consist of silts, sands and gravels sometimes intricately mixed but more often somewhat stratified. Examples of these may be seen in the Snoqualmie, Duwamish, Chehalis and Cowlitz valleys. Similar deposits on a smaller scale are forming along the courses of practically all the streams within the state. These deposits vary in thickness and attain a depth of over 100 feet within the larger valleys. In some places bedrock islands project upwards through the floor of the valley alluvium. Examples of this may be seen in Duwamish Valley in the vicinity of South Park and also at Duwamish Station. Other examples which might be cited are the rock islands projecting upward through the Skagit flats.

TIDAL FLAT DEPOSITS.

Near the mouths of the larger rivers there are broad tidal flats which during high tides are covered with water but during periods of low tide appear as extensive mud flats. Winding sloughs cross these. The deposits are generally composed of a massive bluish gray clay. The best examples of this type are to be found at the south end of Shoalwater Bay, Willapa Harbor, Grays Harbor, the mouth of Columbia River and in many of the small embayments in Puget Sound.

SAND DUNES.

Sand dunes are confined chiefly to the Pacific coast of Washington and Puget Sound. They occur on the long sand spit extending northward from the mouth of the Columbia River to the entrance to Willapa Harbor. Another prominent sand spit extends from the north side of the entrance to Willapa Harbor northward to Grays Harbor. These spits average three miles in width and range up to 25 feet above sea level. They are composed chiefly of wind blown sand which in many places support considerable vegetation.

CHAPTER VII.

GEOLOGIC STRUCTURE AND HISTORY.

GEOLOGIC STRUCTURE.

GENERAL STATEMENT.

Investigations carried on by Russell, Smith and Willis in the central portion of the Cascade Mountains of Washington show that the formations of that area have been warped into a series of folds whose axes trend from southeast to northwest. One of these extends from Columbia River along the axis of the Wenatchee Mountains. A second trends along the Entiat Mountains to the summit of the Cascades. A third lies south of Yakima River. All three are approximately parallel.

A glance at the structure map of western Washington accompanying this report will show three prominent structural features which are designated as differential elongated upwarps. (Plate XXX.) These appear to rank in value with those described by Willis and Smith on the eastern side of the Cascades. There is a prominent downfold extending in a north and south direction the length of the state, nearly at right angles to the upwarps. This downfold is known as the Puget Sound-Cowlitz Valley depression which is a part of a well defined downfold extending from the great valley of California to Queen Charlotte Sound. It is possible, however, that in Washington this downfold may have been formed in part by north-south faulting.

THE SKAGIT-SAN JUAN-VANCOUVER ISLAND UPWARP.

This prominent topographical and structural feature extends from the south side of Skagit Valley and passes out to the Puget Sound depression near the mouth of Skagit River. It extends through the San Juan Islands and thence northwesterly into the heart of Vancouver Island. This apparently is the northwesterly extension of the Entiat warp on the eastern flank of the Cascades. The formations involved along this upwarp are of approximately the same geologic age, viz., Carboniferous and early Mesozoic. They consist of quartzites, slates,

schists, crystalline limestones and a complex series of Mesozoic intrusives. A pronounced sag has been developed nearly at right angles to the axis of this upwarp in the region of the San Juan Islands. This sag is a part of the Puget Sound-Cowlitz basin depression. On both the north and south flanks of this upwarp are parallel axial downfolds, one trending along the Strait of Georgia towards Frazier River and the other along the Strait of Juan de Fuca and across Puget Sound towards the lower valley of Snoqualmie River.

NEWCASTLE-OLYMPIC UPWARP.

The position of this axial upwarp extends from the summit of the Cascades in the vicinity of Mt. Stuart northwesterly through King County and on through the Newcastle Hills and Seattle into Kitsap County. In Kitsap County it involves the Bald Hills and from there extends northwesterly through the main axis of the Olympic Mountains, and possibly out to Cape Flattery. Mt. Olympus lies along this axis. In the Newcastle Hills the older Eocene rocks are brought to the surface and above it so as to form a prominent topographic feature. The later Miocene rocks which overlie the Eocene are absent along the crest of the upwarp but are well developed to the north in the downwarp. In the region where the transverse Puget Sound depression crosses this upwarp, a sag has been developed and only remnants of the bedrock formation project above sea level. They are represented by the Eocene deposits about Duwamish Station, the basaltic masses in the Bald Hills of Kitsap County and the upturned Oligocene formations which flank its north border at Bremerton Inlet. The semi-metamorphosed sediments of the Olympic Mountains have been highly tilted and the strike is approximately parallel to the trend of the axis of the upwarp. A pronounced downwarp lies to the north and parallel to the axis just described. It has been filled with Miocene sediments which in turn have been subjected to extreme folding.

BLACK HILLS UPWARP.

The third upwarp in the western part of the state extends from the Cascades in Lewis County northwesterly through Thurston into Mason and northeastern Garys Harbor County. In this upwarp are involved the high mountain ridges forming the divide between the Cowlitz and Nisqually rivers. In Thurston County it constitutes the low divide between Puget Sound and Grays Harbor. In this region it is crossed by the north-south Puget Sound-Cowlitz Valley depression. To the northwest in the Black Hills the elevations increase to over fifteen hundred feet. The Black Hills are composed of extensive areas of basalt of Eocene age. From this point the upwarp passes into the southern portion of the Olympic Mountains. Its relation in the vicinity of Queniult Lake to the main Olympic axis has not been definitely determined.

On the southwestern side of this upwarp in southwestern Washington the Eocene formations pass below sea level and are covered with extensive deposits of Oligocene and Miocene age. These have also been folded into minor anticlines and synclines which may be seen on the structural map.

Two well-defined anticlinal axes trend in a northwesterly-southeasterly direction through Pacific County but are not to be regarded as of the same importance as the three just described.

Downwarps have already been referred to in the discussion of the upwarps. There are four of these in western Washington. The most northerly lies along the north side of Vancouver Island and extends into Whatcom County. Between the Skagit-Vancouver and the Newcastle-Olympic upwarps, there is a pronounced downfold trending parallel to the Strait of Juan de Fuca southeasterly into Snohomish County. Between the Newcastle-Olympic and Black Hills upwarps there is a downfold whose extent has not been definitely determined. In the Puget Sound Basin area it is deeply filled with glacial drift deposits. A fourth axial downfold trends from Grays Harbor southeasterly to the Cowlitz Basin.

ANTICLINES AND SYNCLINES.

Upon the structural map accompanying this report have been platted all the important anticlinal and synclinal folds which could be definitely determined. These have been grouped into two broad divisions, viz., major and minor anticlines and synclines. The former includes those folds which constitute an important structural unit over a considerable geographical area. The latter are those which have been developed as minor folds on the flanks of or subsidiary to the major folds. One major anticline designated upon the map as the Newcastle anticline passes nearly east and west through central King County. Its actual position as nearly as can be determined is shown on Map B, Plate IV. Its axis swings in a sinuous fashion but still maintains its nearly east to west direction. To the north there is a broad synclinal basin. In the eastern portion of Puget Sound Basin its exact position cannot be absolutely determined. Its northwestern extension, however, can be traced into Jefferson County as has been indicated upon Map C, Plate IV. A second major anticline trends across the Quimper Peninsula from Hood Head to Port Discovery Bay. From Lake Crescent in Clallam County a well-defined synclinal trough extends northwesterly and enters the Strait of Juan de Fuca. Its exact position in the Strait, of course, cannot be determined. The Vancouver Island shore is skirted with lower Miocene strata, dipping at low angles to the southwest, although they are in places involved in minor axial folds transverse to the main synclinal trough. Along the south side of the Strait, minor anticlinal and synclinal folds are well developed from Gettysburg to Cape Flattery. They represent minor wrinkles on the southwest limb of the synclinal trough. The Cape Flattery monocline apparently represents the true southwest limb.

On Vancouver Island between Sooke Bay and Sherringham Point a shallow synclinal trough exists but it is apparently subsidiary to the main synclinal trough of the Strait. All of the above mentioned minor folds are involved in the downfold between the Skagit-Vancouver and Newcastle-Olympic upwarps.

In the vicinity of Seattle and eastward numerous transverse folds have been developed on the flanks of the Newcastle anticline. In the Pierce County coal fields the anticlinal and synclinal folds are pitching to the north. In the Green River area in King County similar folds are pitching southward. Apparently a northwest-southeast downfold intersects them and trends approximately along the boundary line between King and Pierce counties.

In southwestern Washington, Eocene and Miocene deposits have been folded into numerous parallel anticlines and synclines trending North 65° West. One major anticlinal axis trends from the south side of Grays Harbor to the northeastern corner of Pacific County and along it the older Eocene basalts come to the surface. On the northeastern side of this fold the Miocene strata form the surface outcrops and have been folded into a series of parallel minor anticlines and synclines pitching northwesterly towards the ocean.

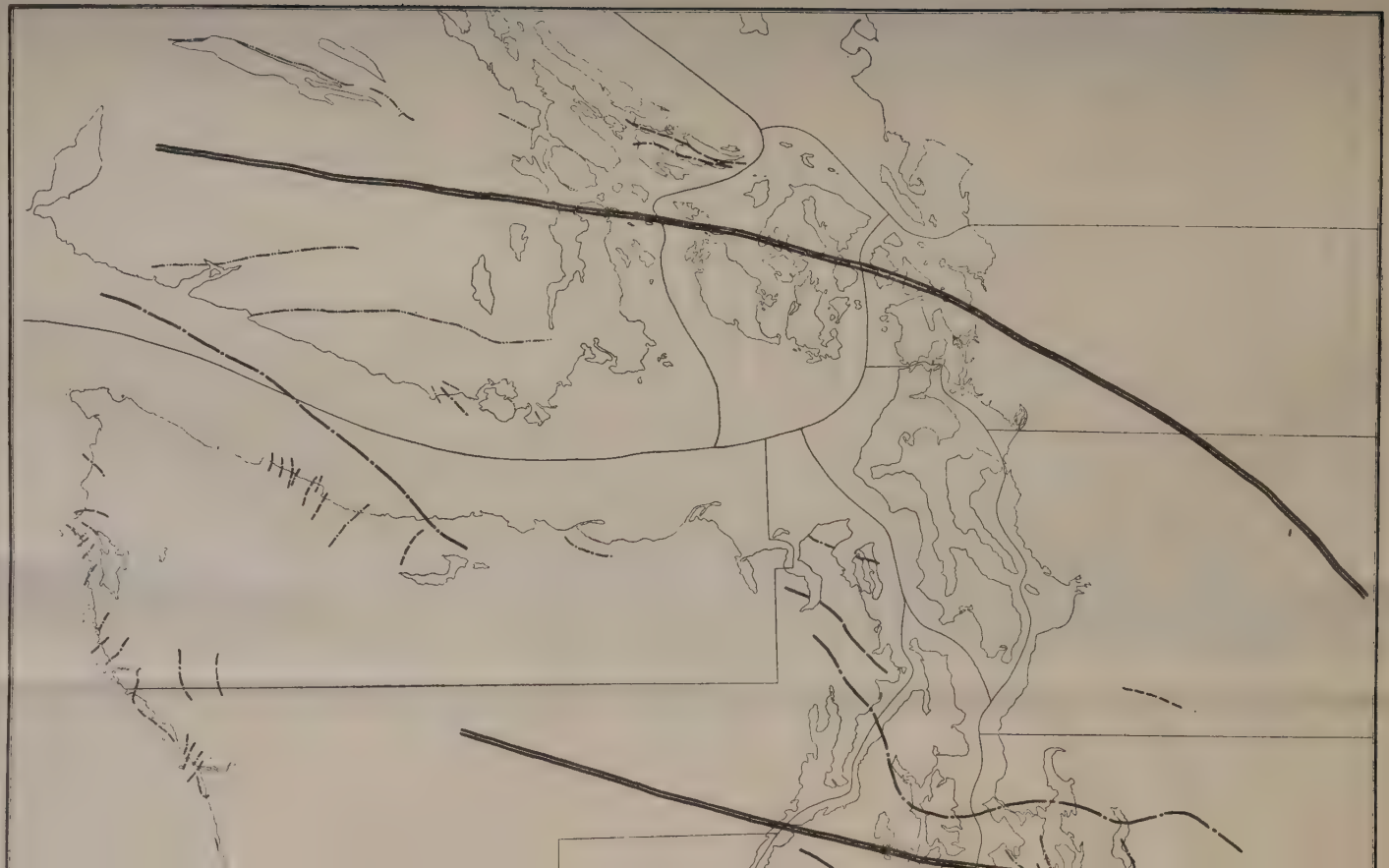
Farther to the southwest a parallel major anticline trends from Shoalwater Bay southeasterly into Wahkiakum County. The core as exposed at the surface is also composed of Eocene basalts. Between the two major anticlines just described a shallow synclinal trough exists. In it only the very basal portion of the Miocene sediments are involved. To the southwest toward Ilwaco several smaller folds occur. The strata involved in them are Oligocene and they occupy a downfold. The Eocene basalts are again brought to the surface at Ilwaco Point. In the vicinity of Fort Columbia on Columbia River, basalt flows occur, interbedded with the lower portion of the Oligocene strata. These minor folds extend across Columbia River and may be seen as shallow folds within the town of Astoria in Oregon.

On the Pacific Coast from Grays Harbor northward to Cape Flattery a large number of folds have been formed in the Hoh formation. A broad anticlinal fold extends from Forks postoffice on the Bogachiel River southward into Jefferson County. Its southward extension has not been definitely determined. To

the west of this anticlinal fold a synclinal fold has been developed approximately parallel to the coast line. The western limb of this syncline has been developed into a series of transverse folds, having an average trend of North 30 East. Nearly all of these are intersected by the coast line and their position has been definitely determined. Their true position may be seen by referring to Map A, Plate IV, as well as on the structural map, Plate XI. The above described structure is terminated by the long axis extending out towards Cape Flattery and perhaps by an extensive fault extending from Point of the Arches southeasterly up Soleduck River.

TIME OF FOLDING.

The three main structural upwarps may have been initiated at the close of the Jurassic. No definitely known Cretaceous rocks are known in the Olympic Mountains. They do, however, skirt the north shore of Vancouver Island and extend into northern Whatcom County. Apparently Vancouver Island, the Olympic Mountains and the northern Cascades south of the Skagit River were land areas during the Cretaceous. The Eocene, Miocene and Pliocene formations are absent from the central portion of the Olympics and Vancouver Island. It would appear that deformational movements produced uplifts along these upwarps so as to bring a part of the sea floor above sea level. A transverse downfold along the Puget Sound-Cowlitz Valley depression perhaps was also initiated at this time. As a result of these earth making movements, it is probable that the embayments in which Eocene sediments accumulated, were formed. At least these movements must have helped to influence their distribution. Near the beginning of the Oligocene epoch movements of the crust in this part of the state seem to again have produced downfolding and upfolding along these same lines of folding. New basins of deposition were developed, chiefly in the synclinal trough along the Strait of Juan de Fuca to King County and from Grays Harbor south to the Columbia River.



At the close of the Oligocene epoch the marine strata which had been deposited during that time were folded and uplifted and apparently raised high above sea level. The localities of greatest uplift appear to have been along the areas of the three upwarps as shown upon the structural map.

Near the close of the Pliocene the Cascade Mountains were brought into their present position. During the elevation of this peneplained surface the formations were being developed into shallow elongated folds as indicated upon the structural map of western Washington. The Pliocene uplift is believed by the writer to have been an intensified upward movement along the axes of the same upwarps which had their beginning possibly at the close of the Jurassic. As a result of studies in the western part of the state it seems probable that differential diastrophic movements were taking place with varying intensity from the Cretaceous to the Pleistocene and along the same major lines of folding or upwarp. The times of most intense movement were at the close of the Jurassic, the Oligocene, the lower Miocene and near the close of the Pliocene. The present topography and structure probably in part owes its origin to diastrophic movements initiated at or near the close of the Jurassic and to a continuation of those movements during the Tertiary in a more or less intensified form. At the close of the Pliocene the most important folding occurred.

FAULTS.

Because of the dense covering of vegetation and of Pleistocene deposits it has been impossible to determine many faults which undoubtedly exist. Detailed studies have been made in the King and Pierce county coal fields and numerous faults were encountered. Many of these show a displacement of only a few feet, while others are displaced more than 1500 feet. The prevailing directions are northwest and southeast. In southwestern Washington many faults of small extent occur but are not of sufficient importance to be represented upon the map of a scale used in this report. North of Cape Elizabeth along the shore a fault occurs which extends southeasterly and intersects

Queniult River about four miles from its mouth. The upper Miocene strata rest against those of the older Hoh formation along the fault plane.

Farther north on the coast a possible fault extends from the north side of Portage Head southeasterly and crosses Hoko River in Section 24, Township 31 North, Range 14 West. From that point it passes into the Olympic Mountains and has not been examined. A similar fault may exist on the south side of Point of Arches and trends parallel to the one just mentioned, but the evidence is not conclusive.

On Vancouver Island two faults occur extending nearly east and west. The south fault extends from Sembrio Point towards Victoria and separates the Eocene basalts on the south from the older Mesozoic metamorphics on the north. The data concerning faulting on Vancouver Island have been determined by Charles H. Clapp of the Canadian Geological Survey* and to him should be given full credit for this information. The basalts which were mapped by him as the Metchosin formation were considered to be of early Mesozoic age but Tejon fossils have been found in the tuff phase at Albert Head, proving it to be of Eocene age. It seems best to incorporate this data as it has a direct bearing on the structure in Washington.

GEOLOGIC HISTORY.

Very little data is at hand concerning the geological history of western Washington during the Paleozoic, especially the earlier half. In the northern Cascade Mountains, in the San Juan Islands and on Vancouver Island, an extensive series of metamorphic rocks are found which in places contain Crinoid remains. The species cannot be exactly determined but they strongly suggest a Carboniferous age. From the lithologic character of the materials occurring within these presumable Carboniferous strata, it is possible to imagine the probable geologic conditions which then existed.

The larger portion of western Washington appears to have been part of an extensive marine area which was probably con-

* Memoir Number 13—Geological Survey of Canada. 1912.

nected with embayments which were definitely known to exist in Idaho, Oregon, Nevada and California. The indications on Vancouver Island and in the northern Cascades point to the occurrence of numerous islands, some of which may have been in the nature of volcanic cones. Volcanic activity appears to have taken place in this region during the Carboniferous. Deposits of volcanic ash as well as lavas are found interbedded with the Carboniferous sedimentaries.

At present there seems to be no way of distinguishing between the Carboniferous and Triassic formations in the western part of the state. Detailed studies in the future may permit such distinctions to be made. As far as we are able to judge at present the geographical and climatic conditions during the Triassic were very similar to those during the Carboniferous. Tropical conditions prevailed during both periods.

The Cascades at this time did not exist in their present condition. The Peshastin formation in eastern Washington, the Gunn Peak formation in the Skykomish valley and the old metamorphic rocks of the Skagit valley are presumably of the same age and were deposited during the Carboniferous and Triassic. If this assumption be correct, the open seas occupied all of northwestern Washington, including the present site of the Cascades. In southwestern Washington and northwestern Oregon the upper surface of the Triassic and Carboniferous rocks is far below sea-level and is covered with an enormous thickness of later Tertiary formations. Nothing is known concerning the character of the Carboniferous and Triassic seas in that region.

Very little is known concerning the Jurassic in western Washington. On the western slope of the Olympic mountains a thick series of semi-metamorphosed strata which have been designated as the Hoh formation are provisionally assigned to the Jurassic. If this assumption be correct, we may consider the present site of the Olympic Mountains as having been under water during Jurassic time.

Towards the close of the Jurassic, volcanic activity began on an extensive scale. Great masses of igneous materials were injected into the earth's crust in the form of batholiths. These were first of basic or ultra basic composition. Following this came intrusions of granodiorite. This igneous activity in Washington was a phase of similar invasions which were common to the entire Pacific Coast from Mexico to Alaska. In the Cascades these intrusives are represented by the great masses of peridotite and Mt. Stuart granodiorite, as well as the Index granodiorite. Accompanying this igneous activity or just following it, important deformational movements began.

No deposits of lower Cretaceous or Knoxville age are known within the state of Washington. The larger part of the state is covered with formations of a later period and it is possible that the lower Cretaceous may be buried beneath. In the northern part of the state the upper Cretaceous or Chico strata are present and represent an embayment which was developed in British Columbia, and extended southward into San Juan and Whatcom counties. This sea extended over the northeastern part of Vancouver Island. Submergence appears to have been rapid during the early part of the Chico epoch but toward the close the seas became shallower as attested to by the massive sandstones and conglomerates which constitute the upper part of the Chico as exposed upon Vancouver Island.

There is no definite evidence concerning the geologic and geographic conditions in western Washington during the early part of the Eocene epoch. Presumably the entire area was slightly elevated above sea level. In southwestern Washington and in the Puget Sound Basin formations of upper Eocene age occur which can be correlated with the Tejon formation of California.

During the upper Eocene the Cascade Mountains were not in existence. The Olympic Mountains were presumably a land area of considerable elevation and were separated from the mountains of Vancouver Island by a downfold which at times was partly submerged. Early during the Tejon epoch south-

western Washington was invaded by an embayment from the ocean. The shore line ultimately reached the present site of the foothills of the Cascades but did not connect with the fresh water lakes on the eastern side. An arm of this embayment extended into the Puget Sound Basin and even for some distance into the Strait of Juan de Fuca. Large estuaries existed to the east of the marine embayments and emptied into them. To the east in the central portion of the present site of the Cascade Mountains there were lakes whose shore lines were probably not far above sea level.

During the progress of the Tejon epoch the surface of the land areas as well as the floor of the embayments were undergoing differential upward and downward movements. The shore lines were advancing and retreating. Estuarine conditions were becoming marine for a time and then reverting back to estuarine. Tropical climates prevailed allowing the development of a rich invertebrate marine fauna as well as a tropical flora. Palms and giant ferns were growing on the low swampy lands bordering the estuaries and lakes. The alternate elevations and depressions of the land caused the growth and burial of tropical forests which are preserved in the form of carbonaceous shales and coal seams. Occasionally basic lavas were being erupted presumably in part through fissures and possibly in part through small volcanic cones. Deposits of ash and flows of lava were formed both on the land and upon the floors of the embayments. In the Cascade Mountains two large lakes were developed. The earlier lake basin allowed the accumulation of the sandstones and shales which have been described as the Swauk formation. This lake was finally drained presumably through one of the estuaries in King and Pierce counties to the marine embayments. The deposits which had formed within it were slightly folded and then invaded by basaltic magmas which arose through numerous parallel fissures and accumulated upon the surface as the Teanaway basalt. Later diastrophic movements developed another drainage basin in which the sediments of the Roslyn formation were laid down. Later this lake was

also drained and the waters presumably found their way to the west into the ocean. Probably the same movements which were disturbing the land areas on the present site of the Cascades were effecting the embayments to the west. It is possible that the great lithologic variations in the character of the estuarine sediments of King and Pierce counties may have had some connection with the draining of Swauk and Roslyn lakes of the central Cascades. In eastern Washington volcanic activity was more or less prevalent during the entire Tertiary period. In western Washington it was almost entirely confined to the Eocene epoch and to the Quaternary. This statement does not apply to the western foothills of the Cascade Mountains.

Early in the Oligocene epoch there was a more general subsidence in the western part of the state. Marine embayments extended slightly farther east than during the Eocene epoch. The extensive estuaries which were in existence during the Eocene disappeared. The marine faunas underwent evolutionary changes and many species characteristic of late Tertiary and recent time made their first appearance. During the progress of Oligocene time the faunas were undergoing changes but even at the close of the epoch the most important genera showed tropical characteristics. During the later portion of the Oligocene epoch the marine embayments became most widely spread. The larger portion of the Puget Sound Basin became an embayment and it is possible that the waters of the ocean gained access through the Strait of Juan de Fuca rather than through southwestern Washington. There may have been a land connection between the Olympic Mountains and the present site of the Cascades.

During both the Eocene and Oligocene and probably the Cretaceous the Olympic Mountains were presumably undergoing vigorous erosion and possibly had reached a condition of peneplanation by the middle of the Oligocene epoch. Many of the higher peaks of the Olympic Range are monadnocks upon the surface of the peneplain.

At the close of the Oligocene there was a slight elevation of the western portion of the state which resulted in the withdrawal of the marine embayments over considerable areas. The Puget Sound Basin appears to have been entirely drained as well as a large portion of the eastern Juan de Fuca downfold. Smaller embayments still existed to the north of Columbia River in Pacific and Wahkiakum counties as well as in the Grays Harbor region. On the whole shallow water seas prevailed and in these a marine fauna lived representative of a colder climate than during the Oligocene. At the close of the lower Miocene the entire Pacific Coast was effected by marked diastrophic movements which brought the entire western portion of Washington above sea level. During the Oligocene and lower Miocene epochs a maximum of 18,000 feet of sediments were deposited in marine embayments. At the close of the lower Miocene these deposits were folded and uplifted.

At the opening of the upper Miocene epoch two local embayments were developed. One of these existed in southwestern Clallam County near the junction of the Solduc and Bogachiel rivers and the other was to the east and north of Grays Harbor. During most of the epoch the waters in these embayments were shallow and contained a marine invertebrate fauna strikingly different from the Oligocene and lower Miocene faunas. The coarse grained and cross bedded character of the sediments indicate the existence of sand bars or spits somewhat similar to those protecting Shoalwater Bay and Grays Harbor to-day. By the close of the Miocene or at least early in the Pliocene these two areas were elevated above sea level. Apparently the land area of the state extended much farther seaward than at the present time.

During the Pliocene epoch all of western as well as eastern Washington was a land area. No marine deposits are known to occur within the state. The present site of the Cascade Mountains was undergoing vigorous erosion and being reduced to a peneplain. The Olympic Mountains were presumably more

highly elevated than the Cascades but were still in a peneplain condition. The pre-Pleistocene topography of the Puget Sound Basin was being developed during this epoch. The history of the Pliocene in Washington is a record of diastrophism and erosion which at the present time is not very well known.

At the close of the Pliocene or early in the Quaternary, mountain making movements were taking place throughout the entire Pacific Coast. The present Cascade Range of Washington and Oregon as well as the Sierra Nevadas of California were uplifted. The Olympic Mountains and the major portion of Vancouver Island were also elevated to an elevation of at least 5,000 feet. During the process of uplift the peneplain surface of the Cascades was slightly warped into a series of northwest and southeast shallow folds. The more important drainage features of the range were partly dependent upon the positions of these folds. In both the Cascades and Olympics the peneplain surfaces were immediately attacked by erosional agencies and the dissection of the uplifted masses begun. In the Olympic Mountains such peaks as Mt. Constance, Angeles, Eleanor, the Brothers and Olympus are residual monadnocks upon the surface of the original peneplain. The principal river valleys of the range have been carved down into the uplifted peneplain surface of the mountains. Upon the uplifted peneplain surface of the Cascade Mountains volcanic cones were built up, such as Mts. Rainier, Baker, Adams, St. Helens and Glacier Peak. Volcanic peaks are entirely absent from the Olympic Mountains. The peaks in that range are composed of metamorphic rock which because of their resistance to erosion have been left as monadnocks.

After the volcanic cones of the Cascades had been formed and the range had undergone vigorous erosion the greater portion of western Washington was subjected to glaciation. The two main advances of the ice, with the record of an interglacial epoch, were described in a previous chapter.

CHAPTER VIII.

PETROLEUM DEPOSITS.

GENERAL STATEMENT.

Petroleum is essentially a mixture of several organic compounds composed for the most part of hydrogen and carbon united in the form of hydrocarbons of variable composition. In association with these there are usually small amounts of oxygen, sulphur and nitrogen. There are various kinds of petroleum but they are usually grouped into three classes—the paraffin type, the asphaltic type and the olefine type. The paraffin types are the source of most of the refined petroleum. The asphaltic types constitute a source for fuel oil and oil asphalt. The olefine type is a source for both fuel and refining purposes. Asphaltic oils when slowly distilled yield a dark residue of asphaltic material which is easily soluble in acids. Paraffin oils when slowly heated yield on reduction a considerable amount of light colored solid hydrocarbons which belong mostly to the paraffin series, and are not easily attacked by acids.

Nearly all asphaltic oils as a rule contain traces of solid paraffin and the majority of paraffin oils contain asphaltic products. As a rule crude petroleums of one type do not contain undue proportions of another type. All crude petroleums possessing either an asphaltic or paraffin character are composed of a mixture of hydrocarbons of different boiling points and densities. The various hydrocarbons constituting such petroleums when subjected to heat are evolved whenever the temperature of their boiling points is reached.

In most oil bearing districts in different parts of the world, the members of the paraffin series of hydrocarbons form one of the chief constituents of petroleum. The higher members of this series which are usually solid are comparatively rare. Methane, CH_4, is the lowest member of this series and occurs as a gas. It is present in solution in large quantities in most oils and also occurs as one of the chief constituents of natural gas.

It is a saturated hydrocarbon and upon analysis normally is found to contain 75 per cent. of hydrogen and 25 per cent. of carbon. In addition to oxygen and nitrogen, other organic constituents which may be present in the form of ash, are calcium, iron, aluminum, copper oxide, silver, arsenic and phosphorous, all of which occur only in exceedingly small amounts.

Petroleum ranges in color from a brownish black to reddish green and yellow and in specific gravity from .780 to 1.0. In a crude state it is a viscous liquid.

SOURCE OF PETROLEUM DEPOSITS.

Geologists are almost unanimously of the opinion that nearly all petroleum deposits are derived from organic sources and not from inorganic. Those who have advanced the inorganic theory of origin are largely chemists. Their ideas have been deduced from experimental data in the laboratory and not as a rule from the geological occurrences of such deposits in the field.

It is believed that in most cases petroleum has arisen from the remains of animal life which formerly was in existence during past geological periods. In some cases plant life has acted as a source. Chemical examinations of living animal organisms show that they are composed largely of fatty materials, while plants are for the most part composed of cellulose. Certain plants of low development in the biologic scale such as diatoms have fats as their chief constituent. Analyses of petroleum compounds show that the chemical substances entering into them are more closely related to fats than to cellulose.

At various times experiments have been performed in the laboratory to bring out certain relationships between the chemical composition of petroleum as compared with that of animal life. In 1888, Engler distilled 490 kilograms of fish oil and obtained a distillate similar to petroleum. Distillation was commenced at a temperature of 320° C, under a pressure of 4 atmospheres. He obtained 60% of distillate which had a specific gravity of 0.8105. From the distillate a light oil indistinguishable from commercial kerosene was obtained.

In most oil bearing districts there appears to be a more or less definite relationship between the presence of fossil animal remains and the strata containing the petroleum deposits. On the island of Trinidad there are extensive asphalt deposits which occur in asphalt lakes. The strata associated with these asphalts contain vast numbers of microscopic marine organisms known as Foraminifera. It is possible that the soft organic tissues of these organisms after having undergone chemical changes may have been the source of the petroleum.

In Scotland there are shales heavily charged with petroleum which are known as oil shales. Upon distillation they yield considerable amounts of liquid petroleum. Associated with these shales are large quantities of fossil fish remains. There may have been a genetic relationship between the petroleum and the original soft organic fats of the fish.

In the Mississippi Basin and in the Appalachian states there are extensive belts of limestone of Palaeozoic age which were in part formed from the hard calcareous remains of marine animal life. These organisms originally contained soft organic tissues. The oil and gas deposits of these areas are associated with the limestones or the overlying or underlying sandstones or shales. There may be a relationship between the petroleum and the original organic life of those regions. In Mexico similar relations exist between the Cretaceous limestones and the deposits of oil.

The soft organic fats from fossil microscopic marine diatoms may have been the source of the petroleum in the oil fields of southern California. During the lower Miocene a portion of the Coast Ranges of California was an arm or embayment of the ocean. Within this embayment there swarmed uncountable numbers of diatoms. During the existence of this sea environmental conditions appear to have been favorable for the continuous development of these forms of life. As a result a formation was built up consisting in part of deposits largely composed of the siliceous remains of diatoms. These siliceous shales are known as diatomaceous shales. They have a direct rela-

tionship to the occurrence of petroleum deposits in the California field. Sandstones occur below, above and interbedded with these shales, and wherever they come in contact with the diatomaceous shales or cherts, they usually contain petroleum. Wherever the sandstones are present and the diatomaceous shales are absent the former are usually barren of petroleum. In other words the sandstones act as a retainer for the oil and gas and the diatomaceous shales have been the source of supply.

To many people there is a general impression that there exists a definite relationship between the occurrences of coal and oil. From a genetic standpoint they are unrelated. Distillations of coal do not give rise to chemical compounds of a character similar to petroleum. Oil may occur in strata of the same geological age as coal deposits. It may even occur with coal but when such a condition obtains, each usually has been derived from a different source.

GEOLOGIC DISTRIBUTION OF PETROLEUM DEPOSITS.

Deposits of petroleum and gas in varying amounts have been found in the strata of all periods from the Cambrian to the Pliocene. As a rule in any one locality petroleum is usually confined to the strata of one or two periods. In the Appalachian and Mississippi Basin regions petroleum and natural gas are found in the Palaeozoic strata. During the Mesozoic and Tertiary these regions were largely land areas and conditions suitable for the development of petroleum did not exist. In Louisiana and southern Texas petroleum and gas are found in the Cretaceous, Eocene and Miocene strata. On the Pacific coast of California there exist strata of Palaeozoic, Mesozoic and Tertiary age. The Palaeozoic formations occur only in scattered areas and are almost barren of petroleum and gas. There are enormous thicknesses of Cretaceous and Tertiary rock in the Coast Ranges. Nearly all the petroleum deposits occur within the Tertiary formations.

Examinations which have been made of oil bearing districts in different parts of the world indicate definitely that petroleum

may occur in strata of any geologic period. During any one period, geologic conditions in one locality may have been favorable for the formation and accumulation of oil and gas and in some other locality perhaps not far away those conditions did not exist. The result is that the rocks formed at the same time in one locality may be entirely barren and in another contain rich deposits of oil.

RELATION OF GEOLOGIC STRUCTURE TO THE OCCURRENCE OF PETROLEUM.

Geologic structure has a very important bearing upon the occurrence of oil and gas. When present in any region they are usually associated with sedimentary rocks. They are very generally absent from igneous or metamorphic rocks. Sedimentary strata are usually composed of alternating layers of sandstone, conglomerate, shale and sometimes limestone. Very often these grade into one another. In most regions oil bearing or other strata are sometimes thoroughly permeated with water which tends to flow as an underground current. In many cases, especially in oil producing districts, this water is heavily charged with chlorides. Sandstone is a much more porous rock than shale and if oil or water, or both, are present they accumulate in it to a greater extent than in the shale, which acts as an impervious layer. As the water and oil circulate through the sandstone zones they tend to partially separate according to the laws of gravity.

As a result of investigations which have been carried on in many parts of the world it has been demonstrated that there are very few instances where sedimentary rocks lie absolutely horizontal. At the present time almost no part of the earth's crust is remaining entirely stationary. Differential movements are taking place resulting in depression in some localities and elevation in others. Sometimes these movements are extremely slow and at other times they take place with considerable rapidity. The combined result of such disturbances is to throw originally horizontal strata into wavelike undulations. These are generally referred to as folds and the upward portion of them

as anticlines. The lower or downfolded portions are spoken of as synclines. The line on the surface following the highest points of an anticlinal fold is known as an anticlinal axis. The angle of slope of the strata on the flanks of an anticline may range from less than one degree to ninety degrees. Sometimes originally horizontal strata may be slightly bulged upward toward a point on the surface. The structure of such a mass would appear similar to a very much flattened cone and the angle of slope of the surface of the cone might vary slightly from place to place. Such structures occurring in nature are known as domes.

When a series of horizontal strata such as have already been described contain water or oil or both, are capped over with impervious shale layers and are then folded into domes or anticlines, the water and oil will tend to circulate along the undulations of the strata. They also tend to maintain the same gravity relations as they formerly did when the strata were horizontal. To a certain extent the water circulates below and the oil above. After the strata have been folded the oil will tend to rise to the highest points possible in the undulating layers of sandstone, and that will be beneath the axes of the anticlines or the apices of the domes. The result is that as the oil and water circulate in the undulating stratum of sandstone a large portion of the petroleum will accumulate toward the axis of the upfold leaving less and less in the downfold or syncline. As a result whenever a well is bored at some point along the axis of an anticline or on the upper portion of a dome and an oil bearing sandstone is tapped, petroleum and gas may rush to the surface in the form of a gusher or it may be necessary to extract it by pumping. If a well be bored along the axis of a syncline and the oil bearing sandstone zone be reached salt water instead of oil may be obtained. These facts have been recognized in practically all the oil producing fields of the world. Such field data as will record the position of anticlines and synclines is among the most important which a geologist seeks in making an examination of an oil district.

In a few instances it happens that there are oil bearing sandstones in which petroleum deposits are present but where water is absent. In such cases, the oil tends to circulate through the sandstone but since no water is present it is not forced to the upper portion of the sandstone zone. It permeates the whole sandstone stratum from top to base or perhaps is present in larger amount near the base. It does not however, as before, tend to accumulate near the axes of anticlines but rather in the synclinal troughs. Such conditions are extremely rare.

It is of very common occurrence in most oil districts that there are several strata of oil bearing sandstone alternating with impervious layers of shale. Each sandstone zone may be considered as an oil reservoir independent of all the other sandstone zones. It would be possible to tap an upper zone and extract all the petroleum within it and not in the least disturb that in the zones beneath. After such a sequence of strata have been formed and folded into anticlines and synclines, they are ordinarily subjected to erosion. Such erosion may be sufficiently vigorous to remove a portion of the overlying shale stratum and allow a small part of the oil bearing sandstone zone to become exposed to the atmosphere. When this occurs the more volatile constituents of the petroleum will tend to evaporate and ultimately leave behind a viscous or solid mass of black asphaltum or light colored paraffin. Such occurrences are to be found on the island of Trinidad in the West Indies and in the Lake Athabaska region of Alberta. It is to be inferred from the occurrence of an asphaltum outcrop upon the surface that at least one oil bearing stratum has by natural processes been destroyed as a petroleum producer, but it does not indicate that there are no more petroleum bearing zones below. In most regions where oil deposits are known to occur and where the associated strata have been folded into anticlines and synclines by minor or major stresses, breaks or cracks have been developed. These are geologically known as faults. They may extend from the surface downward for considerable distances. Occasionally such faults may branch and some of the branches may tap oil

bearing sandstones. When such a condition occurs the lighter constituents of the petroleum may in small amounts travel along these cracks toward the surface. Seepages of oil may reach the surface immediately above its source, or some distance away. It may reach the surface at the axis of an anticline or somewhere along the axis of a syncline or in between. As a result it is apparent that if an underground accumulation of petroleum be present it is not necessarily directly below or in the near vicinity of a surface seepage.

POSSIBLE OCCURRENCES OF PETROLEUM IN WESTERN WASHINGTON.

There are conditions in certain geologic formations within this state which absolutely prohibit the occurrence of petroleum deposits. In certain other formations petroleum might occur and in still others there is definite proof that it is present, but whether in commercial quantities or not, has not been demonstrated. The conditions which would allow of its occurrence are, first, the presence or former presence of some material from which it could be derived; second, the presence of some sedimentary strata which could act as a retaining reservoir; third, the presence of some impervious capping such as a shale or clay stratum to prevent its escape to the surface; fourth, an arching of the strata either into domes or anticlines to allow of its segregation. The presence of metamorphic rocks or igneous rocks are highly unfavorable to the occurrence of petroleum within them. In formations, however, that have been metamorphosed there might be local areas which have escaped or are only semi-metamorphosed. In such formations, if all other conditions are present, petroleum deposits might occur. In the examination of the geology in any particular district it is necessary to determine in how far the above conditions apply, and upon such a basis to decide whether the possibilities for the occurrence of petroleum deposits are favorable or unfavorable.

It often happens that on the surfaces of ponds or marsh areas an irridescent scum appears which is commonly mistaken

for an indication of oil. Occasionally marsh gas may also escape from such areas and convince an observer that oil deposits occur below. In regions where iron oxide forms a part of the cementing material of sediments or is a residual from rock decay, it may also collect as a scum around the opening of a spring or on a stagnant pool of water. A chemical examination of such deposits would show that they have no relation to the occurrence of petroleum.

CASCADE MOUNTAINS.

The Cascade Mountains are composed for the larger part of igneous and metamorphic rocks. A few scattered areas of Eocene and Miocene lacustrine sediments occur in several places, but no large quantities of organic animal remains have been found within them which could give rise to petroleum. In the northern Cascades there are extensive areas of granite and other deep seated rocks. In the southern portion of the Cascades the old granite and metamorphic surface passes down to or below sea level and is covered with an extensive series of lavas and tuffs. The Cascade Mountains as a whole may be eliminated as a possible source for petroleum.

PUGET SOUND BASIN.

GLACIAL DEPOSITS.

The larger portion of the Puget Sound Basin exclusive of that occupied with marine waters is more or less heavily veneered with deposits of glacial drift. These vary extensively in composition from place to place. They are composed of stratified and non-stratified gravels, sands and clays which in most cases have been transported for considerable distances by glaciers. During the advance of the ice sheet into the Puget Sound Region extensive scouring and erosion of the pre-glacial rocks was accomplished. During the retreat of the ice sheet, lakes were developed and into these sediments were being deposited by the adjacent streams. These bodies of water were usually non-marine and forms of animal life living therein were not numerous. Outside of the areas actually involved in these

glacial lakes, glacial material was being deposited by retreating valley glaciers and the streams issuing from them. Such deposits are practically barren of animal life. Because of the character of deposition of all deposits formed, due directly or indirectly to glaciation, there existed no animal life which could possibly have acted as a source for petroleum deposits of commercial value. As a rule the deposits are soft and incoherent and the individual strata do not persist in character for any great distance. Even if small quantities of petroleum had been formed there would have been no means of preventing its escape. It is true there are present in many places very low grade lignite seams which might yield small amounts of gas, but a gas considerably different from that associated with petroleum. The glacial drift of western Washington may be regarded very unfavorable as the source or container for petroleum deposits.

PRE-GLACIAL FORMATIONS.

Beneath the glacial drift and in places extending up through it are sandstones, shales and lavas of Tertiary age. Their subglacial distribution is represented on the geologic maps accompanying this report. During the Eocene the entire Puget Sound region extending easterly into the Cascades was the site of extensive estuaries bordering on the marine waters of the ocean. In these bodies of water sediments consisting of sands, muds and clays were accumulating. Shorelines were shifting from time to time, allowing sediments of marine origin to become interbedded with those of purely estuarine origin. Sediments of the later type predominate throughout the Eocene. A careful examination of these strata fails to reveal the presence of any great quantities of fossil animal life. On the contrary there are extensive deposits of fossil plant life as attested to in the numerous coal seams occurring at intervals throughout the Eocene series. In the Puget Sound region, during the Eocene, conditions were not favorable for the development of marine animal life in sufficient quantities to act as a source for petroleum deposits.

Throughout the Eocene volcanic activity was more or less prevalent. Interbedded with the sediments are extensive flows of andesites and basalts and accumulations of volcanic ash. These extrusive flows came to the surface through fissures rather than through great central volcanic cones. Some of the flows were apparently submarine.

After the close of Eocene time the sedimentary strata together with the volcanic material were uplifted and folded and then subjected to vigorous erosion. In King and Pierce counties post glacial erosion has cut down deeply into the old Eocene rocks, exposing over 10,000 feet of strata. Interbedded with the sandstones and shales are numerous coal seams. The whole series of strata have been thrown into sharply folded anticlines and synclines having a general north and south trend. The axes of these anticlines have been deeply dissected and if any petroleum deposits had been formed they would long ago have been destroyed. There is no evidence to warrant the supposition that oil has ever been present or is present today in the King and Pierce coal fields. Such gas as may be present may be directly associated with lignite deposits and cannot be connected with oil.

In Kitsap County, Eocene basalts outcrop in the hills west of Bremerton and south of Chico. Occasional layers of sandstone are interbedded but of no great extent. The igneous rocks could not possibly have been a source of petroleum and the sandstones which are interbedded are not of sufficient extent to act as a reservoir.

Oligocene strata of marine origin underlie the glacial drift of the northern portion of Puget Sound. They possess a thickness of nearly 10,000 feet and have been folded into anticlines and synclines. The southern limit of these outcrops is along a line extending from Seattle westerly to Bremerton and thence to Hood Canal. In places these strata contain fossil molluscan remains but not in large quantities. A careful search was made for diatomaceous deposits but none were detected. From such fossil life as formerly existed, petroleum

in small amounts might have been formed. However, there are no direct indications of its having been present.

After the close of the Lower Miocene when folding took place, one prominent anticline was developed extending along the Newcastle Hills to Seattle and thence westerly to the Bald hills of Kitsap County. Along the north flank of this fold, numerous minor folds have been developed, all of which pitch to the north. To the north of this anticline, a syncline presumably extends parallel to it. Its northwestern continuation may be seen in Jefferson County south of Port Townsend. To the north of the syncline a second parallel anticlinal axis may exist but because of the great overburden of glacial drift it becomes impossible to definitely prove it. Along the Newcastle anticline, long continued erosion has cut down deeply so as to expose the core composed of Eocene basalts. From Seattle westerly across Kitsap County, the entire series of Miocene strata involved in the north limb of this anticline are standing nearly vertical, or with a steep pitch to the north. The truncated edges of the strata are exposed. Throughout this entire area any oil deposits which may formerly have existed must long ago have escaped. No impervious covering remains as a capping. The glacial drift which lies above in most localities is not sufficiently impervious to prevent its escape, and further these same strata were exposed as above described prior to glaciation. A similar condition appears to obtain farther north near Cathcart station and Snohomish. Southern Kitsap County and western Pierce County are so heavily covered with glacial drift that the geology of the older formations cannot be definitely determined. The character of the strata and the geologic structure which they now assume are such as to prohibit the accumulation and retention of petroleum deposits in commercial quantities in the Eocene and Oligocene formations of the Puget Sound Basin. There may be older formations of pre-Tertiary age lying beneath the Eocene which may be oil bearing or have been capable of producing oil at one time. Concerning such there is absolutely no evidence available. Any

petroleum which may be present in the Eocene rocks has undoubtedly to a large extent seeped into them from such a source.

NORTH SLOPE OF THE OLYMPIC MOUNTAINS

From Cape Flattery eastward to Port Crescent and from the Strait of Juan de Fuca southward for a distance of approximately ten miles the floor upon which the deposits of glacial drift rest is composed of lower Miocene marine sediments. Beneath these are Eocene basalts, sandstones and shales which are exposed at Port Crescent but which are deeply buried below sea-level throughout the remainder of the area.

Deposits of glacial drift vary in thickness and mantle over almost the entire area of the district. Along the coast line and in the canyons of some of the streams the older rocks are exposed. The conditions under which the drift was deposited were approximately the same as in the Puget Sound Basin, and the possibilities for the occurrence of petroleum in the drift are extremely unfavorable.

The surface distribution of the Eocene is represented upon Plates II and IV. Exposures are well developed along the coast in the vicinity of Port Crescent. To the west the Eocene strata pass beneath Oligocene strata. Basalts and andesite constitute the major portion of the Eocene, although narrow bands of sandstone and shale are interbedded. Resting unconformably upon the Eocene are Oligocene and Lower Miocene marine sediments which in the Cape Flattery section attain a maximum thickness of nearly 19,000 feet. These strata in places contain numerous marine fossils. Alternating sandstone and shale bands are present. The whole series of Eocene and Miocene formations have been folded into anticlines and synclines and their approximate position has been indicated upon Plate IV. A synclinal axis extends from near Gettysburg southeasterly to Lake Sutherland. The entire series of strata including those of both Eocene and Oligocene age lying east of the position of the synclinal axis just mentioned are presumably dipping to the southwest and constitute one limb of

the syncline. The strata on the western side of the syncline are dipping to the northeast. From the prevailing northwesterly dip of the strata west from Gettysburg there is direct evidence that they have been folded backwards, thereby developing an anticlinal fold. The exact position of this axis cannot be absolutely determined but its approximate position is fairly certain and has been indicated upon Map A, Plate IV, as extending from a point on the coast line a short distance west of Gettysburg southwesterly to the western end of Lake Crescent. From Twin westerly to Clallam Bay the Oligocene shales and sandstones have been thrown into numerous parallel folds whose axes have a prevailing trend of nearly north and south. The points where these axes intersect the coast line have been definitely determined, but their landward extension is only approximate. From Clallam Bay westerly to Cape Flattery the strata have a prevailing northeasterly dip and constitute a great monoclinal fold pitching away from the long spur extending from the Olympic Mountains west to the Point of the Arches.

East from Freshwater Bay the lower Miocene strata have been folded into a synclinal trough whose axis extends from the vicinity of Port Angeles southeasterly toward Quilcene. It may possibly be a continuation of the syncline existing north of Seattle. An anticlinal axis trends North 70 West from Port Ludlow to Port Discovery Bay but the overlying Oligocene sandstones and shales have been completely removed by erosion exposing the core of Eocene basalts and tuffs.

The following deductions may be made concerning the possibilities for the occurrence of petroleum along the north side of the Olympic peninsula:

1st—The formations involved consist of Eocene basalts, tuffs and sediments, together with an enormous thickness of Oligocene marine fossiliferous strata. The soft organic remains of life which formerly existed in the marine strata could upon slow distillation have produced petroleum products. The more por-

ous sandstones which are present could have acted as reservoirs and the shale belts as impervious cappings.

2nd—The entire series of strata have been folded and if any petroleum deposits were formed they would tend to collect beneath the axes of the anticlines and those areas involved in the synclines would be barren. An inspection of Map A, Plate IV, will indicate the approximate position of the anticlines and synclines.

3rd—No direct indications of petroleum seepages have been seen by the writer in any portion of the area involved.

4th—The final conclusions may be drawn that on the north side of the Olympic peninsula geologic conditions are not such as to absolutely forbid the occurrence of petroleum deposits, although there are no direct indications to suggest their presence. If such deposits are present they will exist beneath the areas indicated upon the accompanying maps as anticlinal axes, where developed within the lower Miocene rocks. Those areas involved in synclinal folds should be considered as barren of possible petroleum deposits.

SOUTHWESTERN WASHINGTON.

GENERAL STATEMENT.

The more detailed description of the geologic and structural conditions obtaining in Southwestern Washington have already been presented in earlier chapters. The formations involved are of Tertiary age and are commonly covered with a very thick soil residuum or with Pleistocene deposits of gravel and sand. The entire Tertiary series is composed of interbedded sedimentaries approximately 15,000 feet in thickness. Whether petroleum is present in these formations or not has not as yet been demonstrated. In the volcanic rocks of the Eocene it cannot be expected to occur. If present at all in southwestern Washington it should be associated with the marine sedimentary phase of the Tertiary. For purposes of discussing the geologic and structural conditions in their relation to the possible occurrence of petroleum deposits in the southwestern portion of the state, it seems best to consider each county as a unit by itself.

PACIFIC AND WAHKIAKUM COUNTIES.

The Eocene of these two counties is composed largely of basalts and basaltic tuffs, which constitute the backbone of the divide between the drainage leading into Columbia River and that into Willapa and Chehalis rivers. It forms a U-shaped area extending from the eastern part of Willapa Harbor southeasterly to the northern part of Wahkiakum and Cowlitz counties. From that point it turns due north. The character of the rock is unfavorable for petroleum deposits to originate within it or if originating without to accumulate within it. There may be strata below which are oil bearing but there is no evidence suggesting their occurrence. If such strata were present there would be no means of determining where the underlying reservoirs were situated. Those areas indicated upon the map of southwestern Washington in Pacific and Wahkiakum counties as Eocene may be regarded as unfavorable for the occurrence of petroleum deposits. (Plate III.)

The Oligocene formation in these counties is confined to two basins. The northernmost of these occupies the basin of Willapa River and the southern area extends east and west along the north side of Columbia River. The strata consist of sandstones and shales of marine origin and carry fossils. They have been folded into anticlines and synclines as previously described in chapters three and four and as designated upon the geologic map on Plate III. The only indications of petroleum which the writer has seen within these formations are some shales which give off a very decided odor of oil. They outcrop in isolated exposures in the hills between Bear River and the town of Ilwaco, in Sections 18 and 19, Township 10 North, Range 10 West. The shales are of a brownish gray color and when heated over a fire burn with a blue flame. An examination of the region indicates considerable faulting. Several basaltic lava flows are interbedded with the sedimentaries and also occur in the form of dikes. The region involved is worthy of a more careful detailed geologic examination and if in the future petroleum deposits are

found to occur in commercial amounts they will undoubtedly be found to have originated in the Oligocene shales.

Whether the strata in other portions of these counties contain oil deposits is unknown. The strata are of such a character and have been folded into anticlines and synclines so that oil, if present, could accumulate. The total evidence from geologic data obtained is only sufficient to warrant the statement that petroleum may be present although no direct evidence to that effect is available.

GRAYS HARBOR COUNTY.

In the northwestern part of the county, in the Queniult Indian reservation, the Hoh formation is present and within that formation farther north oil in small quantities is definitely known to occur. A discussion of that portion of the county will be deferred until later. In the southern and eastern parts of the county, lower and upper Miocene rocks prevail. They consist of shales and sandstones all of which are of marine origin and fossil bearing. These strata have been folded and the position of the anticlines have been approximately inserted upon the geologic map. (Plate III.) No direct indications of petroleum have been seen within this area. Eocene basalts occur in the extreme eastern part of the county and are incapable of containing commercial oil deposits. The Miocene strata may possibly contain petroleum deposits. There is not now sufficient evidence to warrant the supposition that oil is present.

COWLITZ AND LEWIS COUNTIES.

The formations involved in the western part of these counties are of Eocene age and are composed of marine and brackish water sediments together with interbedded basalts and basaltic tuffs. The two latter are incapable of giving rise to or forming reservoirs for petroleum in commercial quantities. The brackish water strata contain no organic animal remains which would be capable of producing oil, although it might travel from some other source and collect in the coarse grained sandstones. The marine fossiliferous sandstones and shales could have pro-

duced oil deposits but there is no evidence to prove that they have done so. The strata have been folded and the structure is such that oil, if present, might collect beneath the axes of the anticlines. Throughout this entire region basalts, marine and brackish water sediments are interbedded and if oil had ever formed in the marine sediments it might have collected either in the marine or in the brackish water strata. A large part of the western portions of these counties is covered with gravels and sands so that the older rocks do not appear at the surface. It is possible that if the strata were entirely exposed there might be seepages where faulting or fracturing had occurred. All that can be said concerning the possibilities for the occurrence of petroleum deposits in western Cowlitz and Lewis counties is that it could have originated in certain marine sandstones and could have accumulated beneath the axes of the anticlines, but no indications are available to suggest that such has been the case.

THURSTON COUNTY.

A large part of this county is covered with glacial drift and outwash gravels in front and south of the terminal moraine. The underlying bed rock where exposed consists of sandstones and lavas of Eocene age. On the areal geologic map accompanying this report those areas which are definitely known to be underlain with Eocene deposits are mapped as such. The areas mapped as glacial drift do not represent the entire area in which drift is present but rather those areas where it is so extensive that the character of the underlying rocks cannot be determined. In the Black Hills, in the western part of the county, basalts prevail and there can be no possibility for the occurrence of petroleum deposits within them. The outwash gravel plains in the central and southern part of the county are almost barren of trees and are covered with numerous small mounds which owe their origin absolutely to glacial causes. These are not gas mounds and have no relation to petroleum.

The sandstones where exposed are chiefly of brackish water origin and in places contain coal seams. The former organic

life which existed in them was plant and not animal and hence could not have furnished fats which are the chief constituents of oils. The marine sediments, however, where present contain upper Eocene fossils and could have acted as a source for petroleum deposits. Where these are interbedded with the brackish water sediments, if oil were ever present it could have seeped into the latter. Interbedded with both brackish water and marine strata are basaltic lavas and tuffs. They apparently were laid down while the sanstones and shales were accumulating and hence would have but little effect upon any oil strata that might have been present. The whole series of Eocene strata have been folded and the positions of the anticlines and synclines have been plotted upon the geologic map (Plate III). There is absolutely no possible means of predicting whether oil deposits are present or not in this field. If they are present they will be found to have accumulated beneath the axes of anticlines and will occur in the more porous sandstones of the Eocene. The Miocene formations are not present as far as available evidence shows.

WESTERN SLOPE OF THE OLYMPIC PENINSULA.

The region from Grays Harbor northward to Cape Flattery is topographically an elevated plain bounded on the west by the Pacific Ocean and on the east by the Olympic Mountains. The surface of this plain ranges in elevation from one to five hundred feet above sea-level, but gradually increases easterly towards the Olympics. To the north it is terminated by the long axial spur extending out to Cape Flattery. The original surface has been deeply dissected by numerous rivers and creeks flowing across it and emptying into the ocean. The more important of these are the Queniult, Raft, Queets, Hoh, Bogachiel and Soleduck rivers.

The formations involved in this region are the Hoh, Montesano and Pleistocene gravels. The approximate distribution of these outcrops is represented upon the areal geologic map (Map A, Plate IV). The entire region is more or less deeply

covered with Pleistocene sands, gravels, and clays, which rest unconformably upon all the older formations. During the Pliocene and prior to the deposition of the Pleistocene fluviatile deposits, the entire costal plain had been deeply dissected and depressed. Large rivers meandered over the surface and as time progressed large quantities of gravels and sands were dropped by these streams. These deposits lie nearly horizontal and range in thickness from a few feet to over 500 feet. Later the country was uplifted and the present streams have since cut down into those Pleistocene deposits and in places even into the older Hoh and Miocene formations. These older strata are generally exposed along the banks of the rivers and along the ocean cliffs.

The Hoh is the most extensively developed of the pre-Pleistocene formations on the western side of the Olympic Mountains. It possesses a thickness of at least ten thousand feet and is composed of massive and banded shales, conglomerates and extensive belts of shaly micaceous sandstones. The latter grade into a distinctly gray sandstone of medium grain which contains angular fragments of slate and of chert, and nearly always considerable amounts of micaceous shales. It is from this phase of the formation that the odor as well as seepages of petroleum are found. In places interbedded with this are soft brown to gray shales.

The Hoh formation has been folded into major and minor anticlines and synclines and the approximate position of these has been platted upon Map A, Plate IV. Insufficient work has been done to determine all the folds involved, but along the coast where exposures are generally well defined the structure has been worked out in detail.

Two prominent anticlines are believed to exist, trending north and south. One of these apparently lies in the floor of the ocean several miles off shore. The minor anticlines and synclines recorded along the shore may be folds developed in the east limb of this major anticline. It is believed that a second approximately parallel major anticline extends south from

Forks in southwestern Clallam County, into Jefferson County. Such an anticlinal fold is definitely known to extend at least as far south as the north boundary of Jefferson County into Section 3, Township 27 North, Range 13 West. Its southward extension has not been traced. It is within this formation that petroleum indications on the west coast of the Olympic Peninsula are directly associated.

The upper Miocene strata are developed in the basin of Quillayute River in Clallam County and have already been described. No petroleum indications have been observed in the formation in this area.

In the region around the mouth of Queniult River, the strata of the upper Miocene or Montesano formation outcrop. They are exposed from a point about one mile north of Cape Elizabeth south to Point Grenville and for a distance inland of about six miles. Beyond, to the east, they presumably exist but are deeply buried beneath a very thick covering of Pleistocene gravels, sands and clays of fluviatile origin. Queniult River, except near its mouth, has not cut down through the Pleistocene to the Miocene rocks.

The region between the south boundary of the Queniult Indian reservation and Grays Harbor is covered with Pleistocene deposits but the Montesano series is believed to form the bed rock basement upon which they rest. In fact, where the Humptulips and Wishkah rivers cut down to bed rock the upper Miocene strata are exposed. With the exception of certain localities at Cape Elizabeth no petroleum indications are known to occur in the formation in this region.

The Pleistocene deposits are devoid of petroleum. At various places gas is reported to arise from swamps lying in these deposits. Upon examination such gas is found to be chiefly methane, derived from decaying vegetable remains in buried swamps. Occasionally iron oxide appears as a coating on the small pools upon the surface of these gravels and sands. It forms an iridescent coating on water very close in appearance to that of oil.

The areal distribution of the Hoh formation is indicated upon Map A, Plate IV. Seepages of oil have been found in a few places. Gas has been found in a number of places. Many localities abound where the odor of petroleum can be detected sometimes at some distance from the outcrop; at other times only when the rock is freshly broken.

SOURCE OF THE PETROLEUM.

No fossil molluscan remains have been found within the Hoh formation. Locally small pockets of carbonaceous shale occur. A microscopic examination of the shales and shaly sandstones shows the presence of large numbers of diatoms. These are not present in sufficient numbers to form a cherty diatomaceous shale, yet in some specimens of shale they are closely packed. Samples collected from the Hoh Head shales revealed the presence of large numbers of these forms of life. In the well at Forks, shale brought up from a depth of 1800 feet, shows the presence of numerous foraminifera. Chemical examinations made of living marine diatoms show the soft organic parts to be composed of organic compounds of a position closely related to that of petroleum.

In the western Olympic region there appears to be no source except from diatomaceous or foraminiferal remains from which such petroleum deposits as occur could have been derived. The scattered areas of Miocene strata are too limited to have been the source. In other regions in the state where the Miocene deposits are more extensively developed no indications of petroleum are known. The rock formation underlying the Hoh formation is unknown. All the older formations in the northwest have been extensively metamorphosed and the probabilities are that such rocks as underlie the Hoh are in that condition. If so, they could hardly supply the organic material. The fact that considerable quantities of diatoms and foraminifera are present in certain portions of the Hoh formation and that it has been demonstrated in other regions that petroleum compounds may have been derived from such sources and further that no other sources in this region are present, indicates that

the petroleum products in the Hoh formation are probably derived from these organisms. The Hoh formation is the only one in the state from which definite evidences of petroleum are known.

There are massive brown sandstones in the formation which could act as retaining reservoirs provided some impervious capping were present. Such reservoirs would be expected to form beneath the axes of the anticlines. Whether such deposits occur in commercial quantities or not can only be determined by drilling on the axes of the anticlines in this formation.

GEOLOGIC CONDITIONS IN SPECIAL AREAS ON THE WEST COAST OF THE OLYMPIC PENINSULA.

Bearing in mind the fact that very small amounts of petroleum are known to occur in the Hoh formation and further that its occurrence in commercial quantities has not been proven, it is possible that petroleum might occur anywhere within the formation provided structural conditions are favorable. In order to fully discuss these conditions, the western portion of the Olympic Peninsula has been separated into districts for description, as follows: Southwestern Clallam County, Ozette Lake Region, Western Jefferson County, and the Queniult Indian Reservation.

SOUTHWESTERN CLALLAM COUNTY.

The area involved in this district embraces Township 28 North, Ranges 14, 13 and part of 12 West. It extends from the ocean on the west to the Olympic Mountains on the east. It is drained by the Soleduck, Calawah and Bogachiel Rivers. The average elevation is 500 feet above sea level, with an increase from west to east.

With the exception of a small area near the forks of the Soleduck and Bogachiel rivers which is upper Miocene, the entire areal geology consists of outcrops of the Hoh formation. Outcrops of this formation appear at intervals along the cliffs of the Bogachiel and Calawah rivers and also in the more highly elevated divide between those rivers in the eastern part of the region under discussion. (Plate XI.) The strike and dip of

the strata at these points have been platted upon this map. All observations taken in the eastern half of Township 28 North, Range 13 West, show a pronounced easterly dip ranging from 35° to 88°. In the western half of this same township and range the strata are dipping to the west from 50 to 60 degrees and continue to do so towards a synclinal basin in the eastern half of Township 28 North, Range 14 West. A well defined anticline crosses Bogachiel River near the boundary between Sections 33 and 34, Township 28 North, Range 13 West. From observations taken to the east and west it apparently extends northerly through Sections 28, 21 and 16 of the same township and range to the town of Forks. To the south it passes into Jefferson County in Section 3, Township 27 North, Range 13 West. This fold for purposes of reference will be designated as the Forks anticline.

A well defined syncline trends nearly north and south through Sections 12, 23, 26, and 35, Township 28 North, Range 14 West. In the western half of this township the Montesano formation rests nearly horizontal upon the steeply dipping truncated edges of the Hoh strata.

Indications of gas and the odor of petroleum occur at intervals along Bogachiel and Calawah rivers. The odor of petroleum is particulaly noticeable in the shaly sandstones in the northeast ¼ of Section 23, Township 28 North, Range 14 West. In Sections 20 and 34 on Bogachiel River and Section 3 on Calawah River, Township 28 North, range 13 West, the rock has a decided odor of petroleum when freshly broken and may be noticed for some distance away as one approaches these localities. In Section 27, Township 28 North, Range 14 West on Bogachiel River the sandy shales have weathered into a bluish gray mud. A very noticeable odor of natural gas can be detected. Several small holes made with a pick handle allow the gas to escape with a sizzling sound. When lighted it will burn in each case for about one minute with a blue flame. A well is being bored by the Washington Oil Company of Seattle in

Section 16, Township 28 North, Range 13 West, south of the town of Forks on Forks Prairie.

QUENIULT RIVER DISTRICT.

The area involved in this district extends from Grays Harbor northward to Queets River and includes the Queniult Indian Reservation. The entire region is an uplifted plateau-like bench with an undulating surface and ranging in elevation from 100 to 400 feet. Along the ocean shore line the cliffs extend from sea level to two hundred feet in elevation. The formations are almost exclusively of sedimentary origin. The only exception is a small patch of basic lava with intercalated sediments at Point Grenville whose age cannot be definitely determined except that it is pre-Miocene. The larger part of the region is covered with horizontally bedded Pleistocene gravels and sands. Along the sea coast and in those places where the rivers have cut down through the gravels the older formations are exposed.

The Hoh formation undoubtedly underlies the younger formations of this entire region but it is exposed at the surface only near the mouth of Queniult River. It outcrops in the cliffs along the ocean in the northwest ¼ of Section 27 and the southwest ¼ of Section 22, Township 22 North, Range 13 West. The exposures extend along the cliff for a distance of about 1500 feet. To the south and possibly also to the north, they are terminated by a fault. The entire exposure is involved in a slide and badly crushed. It is largely composed of brown chocolate colored shales with narrow intercalated layers of sandstone which assume a general strike of North 45° West and a dip of 35° to the northeast.

In the southeast ¼ of Section 6, Township 21 North, Range 12 West on the south side of the big bend in Queniult River there is an outcrop of shale involved in a big slide which has been largely converted over into a bluish gray mud. The shale is of a chocolate brown color and closely resembles that occurring to the northwest along the ocean bluffs. It has been so badly crushed that no strike nor dip could be obtained. Its eastern limits are determined by a well defined fault. The sur-

face between these two localities is heavily covered with gravel and sand, and it cannot be definitely stated that the Hoh shales occupy the intervening area as has been indicated upon the map. The fact that these faults are of considerable size and approximately in line indicates that the Hoh shales probably extend through as a fault block. These are the only surface exposures of the Hoh formation within the area examined and they undoubtedly underlie unconformably the entire area.

Upper Miocene conglomerates and sandstones constitute the formations exposed along the ocean cliffs from Queniult River northward to a point one and one-half miles above Cape Elizabeth. They form the Cape Elizabeth fault block which in itself does not seem to be badly broken. A detailed stratigraphic section has been measured and has been inserted in chapter five. The strata as here exposed strike northeast and southwest and dip at a low angle to the southeast. In the east central portion of Section 34, Township 22 North, Range 13 West, they are slightly folded into a monocline. The axis extends inland in a northeasterly direction.

In the northwest 1/4 of Section 35, Township 22 North, Range 13 West, a gas mound is situated approximately upon the axis of this monoline. It is located a few hundred feet west of the horse trail on the top of the plateau. It has a diameter of about 200 feet and a height of 50 feet, and seems to have been built upon the surface of the low plain. It has existed for some time as large trees are growing upon it. At the summit there is a large crater about four feet in diameter, filled with water and surrounded with mud which is continually issuing forth. Large bubbles of gas almost continuously escape, which when lighted burn with a blue flame. About 100 feet north, on the side of the same mound, there is a smaller gas spring. This mound is located 200 feet above the level of the river and could not reasonably arise from swamp or decayed vegetation which has been buried on the river flat. The gas is probably derived from some depth in the bed rock.

The Hoh formation undoubtedly exists at a considerable distance below the surface. To the north in Jefferson county, gas is very commonly associated with the latter. It is quite probable that the gas issuing from the mound owes its origin to that source; that it has seeped upward into the Miocene sandstones and shaly sandstones and has accumulated in pockets along the axis of the monocline and at the point where the mound has been built up, escapes to the surface. If that be the case, and it seems most probable, it would be impossible to determine at what depth pockets might occur, or how large they might be. The character of the upper Miocene sandstones would allow pockets to form at various depths.

If the gas is of the same origin as that in the Hoh formation farther north, it is possible that oil is associated with the Hoh strata below, but whether in commercial quantities or not there is no possible means of predicting.

QUEETS RIVER DISTRICT.

Topographically this district as in the case of Queniult district farther south is an uplifted plain which has been cut into by Queets River. The entire region is heavily timbered and the surface covered with dense thickets of underbrush. In places it is swampy. The tide extends up Queets River for about one and one-half miles. Three formations are represented within this district. The older is the Hoh and it is important because farther to the north it is the formation with which indications of petroleum are associated. In places above this are shales and sandstones of Miocene age. Resting unconformably upon both the Hoh and Miocene formations are extensive deposits of gravels, sands and clays of Pleistocene age. The latter were deposited by rivers which formerly meandered across this region when it was at a much lower elevation than at present. After uplift the present streams endeavored to cut their channels down through it. In many places they have succeeded as may be seen in the banks of Queets River and in places on Salmon Creek. The general character

of these formations has already been described in chapters two, five and six.

All of the actual pre-Pleistocene rock exposures along Queets River and Salmon Creek belong to the Hoh formation. No seepages of petroleum were seen and no odor detected at any point. However, the formation as exposed here is a continuation of that outcropping along Hoh River, where indications of petroleum are present. Miocene strata are exposed along the coast near the mouth of Raft River. The older Hoh formation was folded and eroded prior to the deposition of the Miocene strata.

The data from which it has been possible to determine the principal structural features of this region have been inserted upon Map A, Plate IV. In certain localities the structure is well defined; in other localities it has been generalized from the better known structural conditions some distance away. In those localities which are covered with Pleistocene deposits it is impossible to say absolutely just what the bed rock structure is beneath. Strikes and dips have been recorded at every possible place along Queets River and on Salmon Creek. Along the Queets the prevailing structure shows a general north to south strike and an easterly dip. In places this strike swings westerly and easterly. All of the outcrops of the bedrock formation on the Queets are of the Hoh formation and it is certain that these strata underlie the entire central and southern part of the area involved in the district.

On Salmon River, in Sections 35 and 36, Township 24 North, Range 12 West, there is a high rocky ridge which has been cut into by stream action. The river flows through two gorges, one on the northwest and one on the southeast side of the big bend in the river. On the northwest side the prevailing strike is North 60° East with a dip of 50° to the northwest. On the southeast bend in the second gorge, the strike is North 30° West with a dip of 25° to the southeast. For a distance of two miles farther up the river this southeasterly dip prevails.

There is direct evidence here that an anticline trends northeast and southwest.

To the north on Queets River, above the junction with Salmon River, the strata are dipping to the northeast and to the east, giving direct evidence of a synclinal axis trending northeast and southwest. Its probable position has been indicated upon the map. Both the anticlinal and synclinal axes, in their southwesterly continuation, pass beneath a thick covering of Pleistocene gravels, sands and clays. It is probable, however, that they tend to merge, and in the area involved in Sections 1, 2, 3, 10, 11, 12, 13 and 14, Township 23 North, Range 13 West, possess a comparatively flat attitude with a low dip to the east.

A minor anticlinal axis exists just south of the mouth of Queets River. It trends about North 40° East. The evidence for this anticline has been obtained from strikes and dips taken around the cliffs in the big bend in the river. It is undoubtedly a minor warp or dome, or spur, on the eastern limb of a large north and south anticline whose main axis lies parallel to the coast line and probably not far from the shore. The eastern limb of this minor anticline has a comparatively low dip to the southeast. The strata are composed chiefly of interbedded sandstones and shales. The axis lies on the low flat ground in the bend in the river and probably extends out toward the shore.

Concerning the possibilities for the occurrence of petroleum deposits within this district the following statement is made: The Hoh formation which contains small seepages northward in Clallam and Jefferson counties is the bed rock formation in this region. No actual seepages, however, have been seen within the strata along Queets River. The strata have been folded into anticlines and synclines as have already been described. Altogether they have a thickness of at least 5,000 feet. There is no possible means of determining whether petroleum deposits occur in commercial quantities or not except by drilling in those localities along the axes of the anticlines. If it should be present there is no means of determining how deep it would

be necessary to drill to reach it. Such deposits as might occur would probably be derived from the shales of the Hoh formation.

HOH RIVER DISTRICT.

The region involved embraces nearly all of western Jefferson County. The major portion of the area is thickly covered with Pleistocene sands and gravels. The bedrock exposures are well developed along the coast line and at intervals along the banks of Hoh River. The detailed examination of the region has been confined to the coast about Hoh Head and the lower part of Hoh River. The more important structural features may be seen by referring to Map A, Plate IV, and also to Plate XII. The interior region has not been examined in sufficient detail to warrant a statement concerning structural conditions.

Near the mouth of Hoh River several smaller creeks have carved out low valleys extending to the river. The highest elevations are less than three hundred feet. The region is heavily timbered and is bordered on the ocean in most places with bold cliffs. There is a broad cove in Section 12 just south of Hoh Head. The land area just back from shore is composed of slide rock in a badly decomposed condition. Hoh Head is a bold rocky point jutting out into the ocean. Between the two points of this head there is a narrow cove. The rock formations in back of this cove are composed of sandy shale and shale all of which are involved in a slide.

There are two formations outcropping in this region. The older is designated as the Hoh and the later as Pleistocene gravels, sands and clays. The Hoh formation is composed of sandstone, shale and conglomerate. The total thickness of this formation, as represented on the western side of the Olympic peninsula, is over 10,000 feet. Within the area of this district only a part of this formation outcrops at the surface. Sandstones and shales occur in equal amounts. The sandstones are massive, generally coarse grained, brown, and only occasionally are shale bands or bedding planes present so as to determine the strike and dip. In places they gradually grade into con-

glomerates. The shales are generally gray to chocolate colored. They often grade into sandy shales and these in turn into shaly sandstones. The shaly sandstones very often become massive and when freshly broken are seen to be composed of angular fragments of slate and quartzite. They possess a gritty appearance but are sometimes banded. The bands are made up of scales of mica and fragments of dark heavier minerals. Sandstone of this character seems to be interbedded with the shales and sandy shales in all localities where the Hoh formation outcrops. The sandy shales and shaly sandstones weather much more rapidly than the belts of massive sandstone and are commonly involved in slides. Ultimately this material passes into a bluish gray mud. It generally possesses a distinct odor of petroleum and in several places yields seepages of it. A careful examination of specimens of the shale reveal the presence of microscopic diatoms.

Within the area of this district there is one very well defined anticline trending northeasterly and passing through the southeast ¼ of Section 12. The north limb of this anticline is well represented in the south point of Hoh Head by massive sandstones striking North 30° East and dipping 80° northwest. One half mile to the southeast, at Rocky Point, massive sandstone forms the southeastern limb of the anticline. Between these two points the formation is composed of shale, sandy shale and shaly sandstone, badly involved in a slide. These shales have a very pronounced odor of oil. The massive sandstone at Hoh Head originally arched over this anticline and connected with the sandstone and conglomerate on the south side. This has since been removed by erosion. The axis of this anticline passes out into the cove as indicated upon the map. Near its trend inland several pits have been sunk. One of these is eighteen feet deep. From its walls oil is slowly seeping into it. All the strata in the near vicinity give a pronounced odor of petroleum.

A second small anticline enters the north side of Hoh Head from the northwest and trends South 60° East. It seems to die

out before crossing Hoh Head. A third anticline possibly crosses the mouth of Hoh River into the northeast ¼ of Section 19 but because of lack of good exposures its exact extent cannot be determined. Its probable position has been indicated upon the accompanying map. A syncline extends from the center of Section 13 northeasterly but its extent cannot be determined. Another syncline enters the north point of Hoh Head from the ocean. It trends South 75 East and dies out before crossing the peninsula. A minor syncline is developed in the cove between the south and north points of Hoh Head. It is possible that this may swing and pass north into the cove on the north side where the trail comes down to the beach.

Examinations of this district show that petroleum and gas are present in very small quantities but whether they exist in commercial amounts or not has not been demonstrated. If they are they should be sought for beneath the anticlinal axes.

QUILLAYUTE RIVER DISTRICT.

The area involved in this region comprises the valley of Quillayute, Bogachiel and Soleduck rivers. It embraces parts of southwestern Clallam and northwestern Jefferson counties. Topographically the district is similar to that to the north in the vicinity of Ozette Lake and to the south towards Grays Harbor. With the exception of a small area near the junction of Bogachiel and Soleduck rivers, which is upper Miocene all of the preglacial formations belong to the Hoh. The general character of the sandstones and shales have already been described in chapter two. The structural data may be referred to on Plate XI. The interpretation of this data when platted indicates the presence of two anticlines and one syncline in which the strata of the Hoh formation are involved. The axes of these folds have a general north-south to northwest-southeast trend. Their approximate position may be referred to upon Plate XI. The axis of the western anticline trends northwesterly parallel to the coast from Hoh River and then swings to the north and passes inland in Section 1, Township 27 North, Range 15 West. The eastern anticline trends southerly in Township 28 North,

Range 13 West, through Sections 2, 11, 16, 21, 28 and 33 into Jefferson County. The axis of the syncline trends southerly through Sections 23, 26 and 35, Township 28 North, Range 14 West. The axis of the syncline is best indicated in the outcrops along Bogachiel River from the northwest ¼ of the northwest ¼ of Section 24, Township 28 North, Range 14 West, to a point about one mile westward down the river. The western anticline should cross Quillayute River near the western boundary of Township 28 North, Range 14 West, about one and one-half miles below the junction of Soleduck and Bogachiel rivers. This conclusion has been arrived at from the projection of the strata inland in accordance with the strike and dip along the coast. The axis of the eastern limb involves the strata in the eastern part of the township forming the eastern boundary of Forks Prairie and underlies the prairie. On the headwaters of Elk Creek, Calawah River and Bear Creek the dip of the strata is easterly. On the western side of Forks Prairie, the surface of the country is low and flat and outcrops of bed rock strata are absent except in places along the banks of Bogachiel River. There the prevailing strike is north and south with a westerly dip. Where the axis of the anticline should cross Bogachiel River in Section 34, Township 28 North, Range 13 West, the sandstones indicate a nearly vertical dip and north to south strike and possess in places an odor of petroleum.

That portion of the formation represented on the surface near the axis of the western anticline is apparently deeply buried along the eastern axis. Whether oil is present in commercial quantities can only be determined by boring upon the axis of one of the anticlines indicated upon one of the accompanying maps of the region. An examination of shales encountered in the well which is being bored by the Washington Oil Company at Forks indicates the presence of numerous species of foraminifera and it is presumably from these organisms that such gas and oil seepages as are present, were originally derived.

OZETTE LAKE DISTRICT.

The area involved in this district occupies Townships 29 and 30 North, Ranges 14 and 15 West. It embraces a belt about twelve miles in width and fifteen in length bordering the coast. It extends from Quillayute River northward to the axial spur extending from the Olympic Mountains outward toward Cape Flattery. The region is densely covered with timber. The surface formations are largely composed of glacial deposits or a very thick veneer of soil. Along the coast the sandstones and shales of the Hoh formation are exposed. Inland they appear at only a very few localities in the cliffs or along the river channels. The later Miocene strata which outcrop both to the south and to the north are absent in this district. The Hoh formation has been folded and the position of the anticlinal and synclinal axes have been inserted upon Map A, Plate IV. The character of the strata has been described in chapter six.

Wherever the gray shaly sandstones outcrop along the coast from the mouth of Quillayute river north to the Point of Arches there is usually a well defined odor of petroleum. In places a white scum issues through cracks and possesses an odor of oil. There is no means of predicting whether oil is present in commercial quantities or not. If present it will presumably occur beneath the anticlinal axes and will be absent along the synclinal troughs. Along the coast line the positions of the anticlinal axes are fairly accurate but inland insufficient data has been obtained to determine the structure. The formation involved, however, is the Hoh with which petroleum indications elsewhere are associated.

CONCLUSIONS.

There seems to be sufficient evidence to warrant considering all of the Cascade Mountains as an extremely unfavorable region for the occurrence of petroleum deposits. In the western part of the state all areas where the formation is composed of basaltic lavas or of metamorphic rocks the same condition prevails. On the north slope of the Olympic Mountains, and in

most parts of southwestern Washington, there are formations present which might possibly contain petroleum deposits although there is no evidence at present available to directly suggest that they are present. On the western slope of the Olympic peninsula there are several small seepages of oil and gas and numerous localities where the odor of oil may be detected. The strata have been folded and oil may occur beneath the axes of the anticlines although it is impossible to determine whether it occurs in commercial quantities or not. Many so called oil seepages reported as occurring in other parts of the state consist only of a scum on water due to decaying vegetation. The gas which often is noted as issuing from pools of water is common marsh gas which is due to the presence of decaying vegetation.

RECORD OF DRILLING OPERATIONS.

COPALIS WELL.

In 1901 a well was drilled by the Olympic Oil Company, which is now out of existence, near the mouth of Copalis River, in Grays Harbor County. This well is reported to have been drilled to a depth of 850 feet and to have encountered very small amounts of oil and gas at several depths. The surface exposures of rock in this region are almost entirely composed of Pleistocene sands and clays. At Copalis Rock, on the beach, gray sandy shales outcrop at the water's edge and appear very similar to the sandy shales and shaly sandstones of the Hoh formation farther north. On account of a crooked hole the well was abandoned. During the same year a well was drilled in the same region by the Eldorado Oil Company to a depth of 350 feet and is said to have passed through sandy shale for the entire depth. No oil was obtained but a flow of artesian water was encountered.

LA PUSH WELL.

The following year a well was drilled by the La Push Oil Company to a depth of 550 feet. The derrick is still standing, but operations ceased later in the same year that drilling began. The well is situated about three miles south of the mouth of

Quillayute River and one-half mile inland from the shore. The formation in this region is composed of Hoh shales and sandstones.

FORKS PRAIRIE WELL.

This well is located in the southeast quarter of Section 9, Township 28 North, Range 13 West, about one mile south of Forks Post Office and two miles north of Bogachiel River in Clallam County. Drilling began in the autumn of 1912 and in December, 1914, the well had reached a depth of 2,050 feet. Gas and small amounts of oil were encountered at several depths. The strata as exposed in the outcrops in this region are a part of the Hoh formation. The well is being sunk upon the axis of an anticline trending nearly north and south. In a number of localities in the near vicinity of the well the strata yield a decided odor of oil and emit small quantities of gas. Gas and small amounts of oil were said to have been encountered at several depths as the well was being sunk. The machinery consists of a standard rig operated by steam power. Boring was started with a 16-inch casing and continued to a depth of 100 feet. The following statement is the record of casing used in this well:

100 feet 16-inch.
300 feet 12½-inch.
1062 feet 10-inch.
1550 feet 8-inch.
1980 feet 6¼-inch.

HOH HEAD WELL.

This well is situated in Section 12, Township 26 North, Range 14 West, about two miles north of the mouth of Hoh River in western Jefferson County. The formation in this vicinity consists of shales and sandstones of the Hoh formation which have been folded into anticlines and synclines. The Hoh Head well is being drilled on the axis of a northwest to southeast anticline immediately south of Hoh Head. Drilling was begun in September, 1913, and continued to a depth of 901 feet. The following log has been furnished by the Jefferson Oil Com-

pany. Wherever the term slate is employed it presumably refers to a hardened shale.

	Feet
Mud	9
Sand	5
Shale	23
Shale	17
Sand	5
Shale and sand	5
Shale	20
Sand	5
Shale	5
Shale and sand	5
Shale	35
Shale and sand	5
Shale	25
Sand	3
Shale	37
Sand	3
Shale	7
Sand	4
Slate	26
Sand	5
Slate	20
Slate and sand	5
Slate	15
Sand and slate	20
Slate	16
Sand (little gas)	3
Slate	26
Sand (gas)	2
Slate	38
Slate	40
Slate	5
Sand and slate	86
Hard sand	5
Sand and shale	86
Hard shale	14
Shale	11
Sand	8
Shale (big showing of gas)	14
Sand	14
Shale	9
Sand and shale (heavy gas)	5
Sand (oil and gas)	105
Sand and shale	40
Sand	15
Sand and shale	40
Sand (very heavy gas)	10
Total	901

On June 30th, 1914, a second well was started a short distance from well No. 2. Up to the present time this well has been sunk to a depth of 986 feet. The strata passed through was

similar to that encountered in well Number 1. The following is a list of the casing used:

44 feet 18-inch.
78 feet 15½-inch.
331 feet 12½-inch.
376 feet 10-inch.
766 feet 8-inch.
986 feet 6-inch.

This property has been operated by the Jefferson Oil Company of Aberdeen.

QEUNIULT WELL.

Immediately north of the mouth of Queniult River and south of Cape Elizabeth in Section 35, Township 22 North, Range 13 West a well was drilled by the Indian Oil Company. The formation involved in this region is the Montesano or upper Miocene. Just south of Cape Elizabeth a minor flexure in the form of a monoclinal fold extends northeast and southwest. On the surface of the bench at an elevation of about 250 feet a mound has been built up and at the apex of the mound there is a small crater filled with water from which gas is continuously bubbling forth. Within a few feet of the apex a well has been sunk to a depth of over 500 feet. In October, 1914, a new well was started near by and was sunk to a depth of 458 feet. The well was started with 10-inch casing. The machinery consists of a rotary rig operated by steam power.

WILLAPA WELL.

This well was drilled by the Willapa Harbor Oil Company near the town of Raymond, Pacific County. The formations encountered consist of shales and sandstones of Oligocene age. Drilling was begun on August 29th, 1914, and on October 17th of the same year a depth of 1,445 feet had been reached. The following log has been reported by the company:

	Feet
Clay soil	6
Clay and sandstone	34
Dark shale	1005
Sand with indications of oil	6
Shale	344
Sand with shells	50
Total thickness	1445

Drilling was started with ten-inch casing and continued with such to a depth of 350 feet. From the 350-foot level 8½-inch casing was used to a depth of 1,154 feet. Below that depth 6¼-inch casing was employed.

CHICO WELL.

This property is owned by the Kitsap Oil and Development Company of Bremerton, Washington, and is located in Section 5, Township 24 North, Range 1 East, near Chico, in Kitsap County. Drilling was begun in December, 1913, and in December, 1914, a depth of 1,408 feet had been reached. A standard rig with hydraulic circulator was used and operated by steam power. Use was made of the following sized casings: 12½-inch for the first 170 feet; 10-inch for the next 450 feet; 8-inch for the following 875 feet and 6-inch for the remainder.

This well was drilled on the north flank of the Newcastle anticline. The surface formations are composed of glacial drift. Below the drift are steeply tilted sandstones and shales of the middle Oligocene formation. No log is available for use in this report.

BALLARD WELL.

This well is located in Ballard in the northwestern part of Seattle. The surface formations are composed of very thick deposits of glacial drift which are presumably underlain with shales and sandstones of Oligocene age. In December, 1914, the well had been drilled to a depth of 1,700 feet. The well was started with 15-inch casing and later reduced to 12-inch, 10-inch, 8-inch and finally 6¼-inch casing. A standard rig was installed and operated with oil for fuel.

PACIFIC STATES WELL.

This property is located in Section 15, Township 15 North, Range 3 West, in Thurston County. Drilling was started in April, 1914, by the Pacific States Oil Company, and in December, 1914, a depth of 750 feet had been attained. Operations began with a Number 27 Star rig, but later a standard

rig was installed. The well was started with 12-inch casing and at the present level a ten-inch was employed.

OILFIELD WELL.

This property is owned by the Home Oil Company of Seattle and is located in King County in Section 12, Township 34 North, Range 5 East. Drilling was begun in November, 1914, and in January of the following year a depth of 316 feet was reported. The well was started with 12-inch casing and a Keystone rig. The geologic formation in this region is the estuarine phase of the Tejon Eocene but the surface deposits are composed of glacial drift. The Eocene sandstones and shales are a part of the south limb of the Newcastle anticline.

APPENDIX.

FAUNAL LOCALITIES IN WESTERN WASHINGTON.*

1

One and one-half miles east of Vader, Lewis County, on the west bank of Cowlitz River in massive sandy shales of marine origin, situated in Section 27, Township 11 North, Range 2 West. Tejon series, upper Eocene. Old locality 3003.

2

On Olequa Creek about one mile above the junction of Olequa and Stillwater creeks, back of the old Cantwell place, in Section 29, Township 11 North, Range 2 West. Tejon series, upper Eocene. Old locality 3002.

3

On a small creek about one third mile from its junction with Brinn Creek, under an old bridge, in Section 25, Township 11 North, Range 3 West. Tejon series, upper Eocene. Old locality 3001.

5

In Lewis County at a ledge just above the junction of Olequa and Stillwater creeks at Vader in Section 32, Township 11 North, Range 2 West. Upper Eocene. Old locality 3004.

6

In Lewis County one mile west of junction of Stillwater and Olequa creeks on the former in Section 30, Township 11 North, Range 2 West. Upper Eocene, Old locality 3005.

7

On Coal Creek, Cowlitz County, one and one-half miles north from Inman Polson Logging Company's store.

8

In Coal Creek, Cowlitz County, one mile north from Inman Polson Logging Company's store, in brackish water shales, in Section 35, Township 9 North, Range 3 West. Old locality 3007.

9

In Northern Pacific Railway cut one hundred feet east of Seattle Brewing & Malting Company's brewery at Georgetown, South Seattle, in Section 20, Township 24 North, Range 4 East. Oligocene. Old locality 3008.

10

About one thousand feet south of Alki Point, West Seattle, in Oligocene shales outcropping at the water's edge in Section 15, Township 24 North, Range 3 East. Old locality 3009.

---

* From Tertiary Faunal Horizons of Western Washington, University of Washington Publications in Geology, Vol. I, No. 1, pp. 8-22.

11

At northeast corner of rock outlier at Duwamish station in Section 10, Township 23 North, Range 4 East. Tejon series, upper Eocene. Marine sandstone. Old locality 3010.

12

In Northern Pacific Railway cut one-half mile north of Cathcart Station, Snohomish County, in Section 6, Township 27 North, Range 6 East. Locally known as Fiddlers Bluff. Oligocene. Old locality 3011.

13

In marine sandstones on north side of Restoration Point, Kitsap County, opposite Seattle, in Section 12, Township 24 North, Range 2 East. Oligocene. Old locality 3012.

14

On the south fork of Ostrander Creek two hundred feet south from a point where the logging road crosses, which is 1130 feet from the town of Ostrander. In Section 12, Township 8 North, Range 2 West, in brackish water upper Eocene shales.

18

In Cowlitz County in Coal Creek 6500 feet up creek from Inman Polson Logging Company's store. In section 35, Township 9 North, Range 3 West. Upper Eocene. Old locality 135.

20

In Cowlitz County 13,000 feet up Coal Creek from wagon bridge crossing. Upper Eocene. Old locality 136.

21

In Cowlitz County 14,000 feet up Coal Creek from wagon bridge crossing. Upper Eocene. Old locality 137-B.

22

On east side of Ilwaco Point in Section 4, Township 9 North, Range 11 West, in shales which are interbedded with basalts. At traverse station 32.

23

In bluff on north side of Columbia River one-half mile east of the town of Ilwaco in Section 34, Township 10 North, Range 9 West. Probably Oligocene.

24

At Knappton, Pacific County, on north side of Columbia River in bluff back of cook house of Knappton Lumber Mill in Section 8, Township 9 North, Range 9 West. Oligocene. Old locality 139.

25

In Pacific County in bank of Nasel River two and one-half miles east of the town of Nasel in Section 11, Township 10 North, Range 9 West. Oligocene. Old locality 140.

27

In Pacific County 700 feet up Alder Creek from its junction with the east fork of Nasel River in Section 15, Township 11 North, Range 8 West, in a fine dark colored tuffaceous shale interbedded with tuffs and basalts. Oligocene. Old locality 151.

28

In Pacific County 12,000 feet up Hull Creek from the hotel at town of Gray's River in Section 6, Township 10 North, Range 7 West. Oligocene. Old locality 154.

29

In Pacific County 15,000 feet up Hull Creek from the hotel at town of Gray's River in Section 6, Township 10 North, Range 7 West. Oligocene. Old locality 155.

30

Sea cliff between Point Grenville and Taholah in Section 13, Township 21 North, Range 13 West. Upper Miocene.

31

In railway cut, O.-W. R. R. & N. Co., one-half mile west of Lincoln Creek Station, Lewis County, in Section 36, Township 15 North, Range 3 West. Oligocene. Old locality 181.

32

West of the county wagon bridge over Lincoln Creek in sandy shale, near Lincoln Creek Station. Old locality 180.

33

Six thousand feet east of Helsing Junction on the O.-W. R. R. & N. Co. in Thurston County. Eocene. Old locality 182.

34

In Pacific County on Grays River two miles beyond its junction with Blaney Creek in Section 19, Township 11 North, Range 6 West, in a dark tuffaceous shale. Oligocene. Old locality 158.

35

In Pacific County on Nemah River at wagon bridge crossing, four miles east of Nemah post office in Section 33, Township 12 North, Range 8 West. Shales interbedded with basalt. Old locality 167.

36

Exposure at old wagon road trestle along Willapa River at the town of Willapa. In Section 22, Township 14 North, Range 7 West. Oligocene. Old locality 170.

37

In Pacific County at Northern Pacific Railway bridge below Lebam Station in Section 6, Township 12 North, Range 7 West. Oligocene. Old locality 175.

38

At bridge over Chehalis River northwest of Pe Ell station at power station in Section 34, Township 13 North, Range 5 West. Old locality 176.

39

One mile northwest of Pe Ell station in Lewis County on west side of Chehalis River, in Section 33, Township 13 North, Range 5 West Old locality 177 A.

40

In Northern Pacific Railway cut 67 miles north of Portland.

41

In bank of small creek below Booth's house near junction with Stillwater Creek, in Section 25, Township 11 North, Range 3 West.

42

In railway cut O.-W. R. R. & N. Co. two thousand feet east of the Oakville wagon bridge over Chehalis River, in Section 1, Township 15 North, Range 5 West. Upper Eocene. Old locality 184.

43

In the bluff of Lankner Creek, Grays Harbor County, 16,000 feet up from the O.-W. R. R. & N. Co. crossing in Section 25, Township 17 North, Range 6 West. Oligocene. Old locality 185.

44

In the bluff of Lankner Creek, Grays Harbor County, 18,000 feet up from the O.-W. R. R. & N. Co. crossing in Section 25, Township 17 North, Range 6 West. Oligocene. Old locality 187.

45

In the bluff of Lankner Creek, Grays Harbor County, 25,000 feet up from the O.-W. R. R. & N. Co. crossing in Section 33, Township 17 North, Range 6 West.

46

In Grays Harbor County in O.-W. R. R. & N. Co. cut at culvert 38 east, 24,000 feet west from South Elma, in Section 7, Township 17 North, Range 6 West. Upper Miocene. Old locality 263.

47

Chicago, Milwaukee & St. Paul Railway cut 1,000 feet south from O.-W. R. R. & N. Co.'s track in Section 29, Township 17 North, Range 8 West. Lower Miocene.

49

In Section 25, Township 16 North, Range 8 West, on North River, Grays Harbor County. Lower Miocene.

50

In the banks of Wynoochee River, Grays Harbor County, 35,000 feet north of Otter Postoffice and 12,000 feet south of Reinkens' farm in Section 22, Township 19 North, Range 8 West. Upper Miocene.

51

Five hundred feet north of locality 50 on Wynoochee River, Grays Harbor County.

52

In bluff on Wishkah River, northwestern part of Aberdeen, at a point where road to Grand Forks first reaches river after leaving Aberdeen in Section 9, Township 17 North, Range 9 West. Upper Miocene. Old locality 711.

53

Wahkiakum County in west bank of Alockaman River in Section 35, Township 10 North, Range 5 West. Lower Miocene. Old locality number 210. *Arca montereyana* abundant in nodules.

54

Four hundred feet south of locality number 53 in west bank of Alockaman River. Fossils abundant. Lower Miocene. Old locality 211.

56

In bank of creek in NW¼ of section 6, Township 9 North, Range 5 West, in Wahkiakum County. Oligocene. Old locality 213.

57

In bluff on branch of Wilson Creek in Section 36, Township 10 North, Range 6 West, Wahkiakum County. Oligocene. Old locality 214.

58

Nasel River. On Pentler's ranch, one mile west of point where wagon road crosses to south side. Oligocene.

59

On Fossil Creek near log dam in east part of Section 10 and west part of Section 11, Township 10 North, Range 6 West, in Wahkiakum County. Oligocene. Old locality 29.

60

Bluff on Chehalis River along O.-W. R. R. & N. Co. track at milepost 37, about four miles west of South Elma, in Section 11, Township 17 North, Range 7 West. Upper Miocene. Old locality 50.

61

Vance logging road at old milepost in coarse grained sandstone in Section 28, Township 18 North, Range 6 West. Upper Miocene. Old locality 51.

63

East branch of Clements logging road south of Montesano in Grays Harbor County in the Northwest quarter of Section 28, Township 17 North, Range 7 West. Lower Miocene. Old locality 54.

64

East branch of Clements logging road one-half mile east of where county wagon road crosses, in Section 27, Township 17 North, Range 7 West. Lower Miocene. Old locality 55.

65

On east branch of Clements logging road one-half mile east of where county wagon road crosses in Section 29, Township 17 North, Range 7 West. Lower Miocene. Old locality 56.

66

On east branch of Clements logging road, one mile west of county wagon road intersection in Section 29, Township 17 North, Range 7 West. Lower Miocene. Old locality 57.

67

Bluff on Chehalis Logging Company road one mile west of Montesano in Section 6, Township 17 North, Range 7 West. Lower Miocene. Old locality 58.

68

Logging railway cut on Sylvia Creek in a conglomerate of upper Miocene age, in Section 32, Township 18 North, Range 7 West. Old locality 59.

69

Along logging railway in cut on Sylvia Creek, one-half mile north of locality 68 in conglomerates. Upper Miocene.

70

Five hundred feet north of junction of north branch of east fork of Wilson Creek in Wahkiakum County on former, in Section 36, Township 10 North, Range 6 West.

71

Two miles up middle fork of Skamokawa River from junction with main river in Wahkiakum County, Section 32, Township 10 North, Range 6 West. Oligocene. Old locality 216.

72

Wahkiakum County, on McDonald Creek, two miles above its junction with the middle fork of Wilson Creek, in Section 28, Township 10 North, Range 6 West. Oligocene. Old locality 217.

73

Station 31 on Nasel River traverse line, Pacific County, Section 6, Township 10 North, Range 8 West. Oligocene. Old locality 223.

74

Station 34, Nasel River traverse line, Pacific County, in Section 6, Township 10 North, Range 8 West. Oligocene. Old locality 224 a.

75

Station 73, Nasel River traverse line, Pacific County, in Section 25, Township 11 North, Range 9 West. Oligocene. Old locality 229.

76

Station 16, Nasel River traverse line, Pacific County, in Section 6, Township 10 North, Range 8 West. Oligocene. Old locality 231.

77

Station 22, Nasel River traverse line, Pacific County, in Section 6, Township 10 North, Range 8 West. Lower Miocene. Old locality 233.

80

1600 feet above first railroad bridge on Willapa River below Holcomb in Section 25, Township 13 North, Range 8 West. In Oligocene shales. Old locality 241.

81

One-half mile up Green Creek from Willapa River in Pacific County in Section 26, Township 13 North, Range 8 West. Oligocene. Old locality 241.

82

1200 feet above highway bridge near mouth of Green Creek. Old locality 242.

83

7050 feet up Green Creek from Willapa River, Pacific County. Oligocene. Old locality 243.

84

7750 feet up Green Creek from Willapa River, Pacific County. Oligocene. Old locality 244.

85

8250 feet up Green Creek from Willapa River, Pacific County, in Oligocene shales. Old locality 245.

86

8880 feet up Green Creek from Willapa River, Pacific County, in Oligocene shales. Old locality 246.

87

11,350 feet up Green Creek from Willapa River, Pacific County, in Oligocene shales. Old locality 247.

90

In bluff north side Chehalis River 2240 feet west of Porter station along Northern Pacific Railway track. Oligocene. Grays Harbor County in Section 21, Township 17 North, Range 5 West. Old locality 260.

92

On North River branch of Chicago, Milwaukee & St. Paul Railway grade 3000 feet north of point where wagon road goes up Vesta Creek, near Chamber's farm, Grays Harbor County, Section 25, Township 16 North, Range 8 West. Lower Miocene. Old locality 265.

93

22,000 feet up Wynoochee River from Otter Post Office, in SW¼ of Section 5, Township 18 North, Range 8 West. Upper Miocene. Old locality 270.

94

Bluff back of Lincoln School in Hoquiam, Grays Harbor County. Poorly preserved specimens of *Scutella gabbi*. Upper Miocene.

96

28,000 feet up Falls Creek from Brooklyn in Pacific County, in Section 10, Township 15 North, Range 6 West. Old locality 281.

97

In Section 34, Township 15 North, Range 7 West, in a small creek entering North River just north of Grays Harbor-Pacific County line. Lower Miocene. Old locality 282.

98

Bluff on Willapa River, between Holcomb and the railroad bridge west of town in Section 36, Township 13 North, Range 8 West. Oligocene. Old locality 283.

99

On Wishkah River wagon road one mile north of Aberdeen in Section 4, Township 17 North, Range 9 West. Upper Miocene. Old locality 191.

100

On wagon road cut up Wishkah River road one and one-half miles below Wishkah Post Office in Section 11, Township 18 North, Range 9 West. Old locality 192.

101

One mile beyond Wishkah Post office in bank of river in Section 35, Township 19 North, Range 9 West. Upper Miocene. Old locality 193.

102

Station 837 Neah Bay-Cape Flattery traverse. About one-half mile west of Kaitlab Point in the cliffs. Oligocene.

103

At station 996, Neah Bay-Cape Flattery traverse. About one mile west of Kaitlab Point in the sea cliffs. Lower Miocene.

105

About 200 feet east of Slip Point light house, west of Clallam Bay on coast line. Lower Miocene. Old locality 92.

109 to 109

At base of cliff, Slip Point, east of Clallam Bay on coast. Lower Miocene. Old locality 92A.

111

Mouth of Maxfield Creek in southwest quarter of northwest quarter of Section 28, Township 28 North, Range 14 West. Old locality 94.

112

Southeast quarter of northwest quarter of Section 16, Township 28 North, Range 14 West. Old locality 95.

113

Twenty feet east of line of Lot 1, Section 27, Township 28 North, Range 14 West.

114

Northeast quarter of northwest quarter of Section 27, Township 28 North, Range 14 West. Old locality 96.

115

In brown sandstone on Soleduck River bluff about center of Section 20, Township 28 North, Range 14 West. Old locality 97.

117

Station 161, Wishkah River traverse. In bank of river in Section 30, Township 20 North, Range 8 West, Grays Harbor County. Upper Miocene. Old locality 2032.

118

Middle fork of Wishkah River 300 feet south of locality 117 in bank of river. Upper Miocene. Old locality 2033.

119

Middle fork of Wishkah River 1200 feet south of locality 117 in bank of river. Upper Miocene. Old locality 2033A.

120

Middle fork of Wishkah River 100 feet south of locality 117 in bank of river. Upper Miocene. Old locality 2034.

121

Middle branch of Wishkah River in east central part of Section 31, Township 20 North, Range 8 West. Upper Miocene. Old locality 2035.

122

Middle branch of Wishkah River, 800 feet west of locality 121. Upper Miocene. Old locality 2036.

123

Middle branch of Wishkah River in south central part of Section 36, Township 20 North, Range 9 West. Upper Miocene. Old locality 2037.

124

Middle branch of Wishkah River 1000 feet southwest of locality 123. Upper Miocene. Old locality 2038.

125

Middle branch of Wishkah River in southwest quarter of Section 1, Township 19 North, Range 9 West. Upper Miocene. Old locality 2039.

126

One and one-half miles north of Hoquiam on road to Copalis in a cut on west side of road, in Section 34, Township 18 North, Range 10 West. Upper Miocene. Old locality 901.

128

At survey stake 388 on North River branch of Chicago, Milwaukee & St. Paul Railway in Grays Harbor County in Section 29, Township 17 North, Range 8 West. Lower Miocene. Old locality 903.

129

In south bank of south fork of Stillaguamish River in Section 11, Township 30 North, Range 6 East, Snohomish County. Oligocene.

130

On west bank of Wilson Creek, Pacific County, one mile west of Willapa Post Office, in Section 21, Township 14 North, Range 8 West. Oligocene.

131

Logging railroad cut one mile west of Montesano, Grays Harbor County, in Section 1, Township 17 North, Range 8 West. Lower Miocene.

132

North River branch of Chicago, Milwaukee & St. Paul Railway, 300 feet south and up hill from culvert 38 of O.-W. R. R. & N. Co. track in Section 29, Township 17 North, Range 8 West. Lower Miocene. Old locality 1000.

133

North River branch of Chicago, Milwaukee & St. Paul Railway, 200 feet to the southwest from locality 132.

135

Railway cut on North River branch of Chicago, Milwaukee & St. Paul Railway in the northeast quarter of the northwest quarter of Section 29, Township 17 North, Range 8 West. Lower Miocene. Old locality 1008.

136

Railroad cut 300 feet west of locality 135. Lower Miocene. Old locality 1009.

137

Bluff in wagon road along east side of Wynoochee River one mile south of Bitter Creek in Section 35, Township 18 North, Range 8 West. Lower Miocene.

138

In bank of Wynoochee River along wagon road 600 feet north of station 137. Lower Miocene.

140

Cut in south side of "Think of Me" hill in East Aberdeen, Grays Harbor County. Upper Miocene.

141

Northern Pacific Railway cut 3000 feet east of locality 140, Aberdeen.

142

Northern Pacific Railway cut 270 feet east of locality 141, Aberdeen.

144

Stratum 20 feet stratigraphically above that at locality 142 in the Northern Pacific Railway cut east of Aberdeen.

145

In cut at Aberdeen, Grays Harbor County, at corner Summit and Chehalis streets.

146

Survey stake 110 on Chicago, Milwaukee & St. Paul Railway at Cosmopolis, Grays Harbor County, in section 23, Township 17 North, Range 9 West. Upper Miocene.

147

Railroad cut on Chicago, Milwaukee & St. Paul Railway track 400 feet east of locality 146.

148

Ocean bluff one mile north of Point Grenville in Section 13, Township 21 North. Range 13 West. Upper Miocene.

151

Log dam number 35 on the west fork of Wishkah River in Section 35, Township 20 North, Range 9 West. Upper Miocene. Old locality number 100,006.

152

One hundred feet south of locality 151 in canyon of West branch of Wishkah River.

154

North side of Restoration Point, Kitsap County. Oligocene.

155

Small creek emptying into Coal Creek, King County in Section 23, Township 24 North, Range 5 East. Oligocene.

156

Southeast quarter, Section 13, Township 24 North, Range 5 East, one mile west of Lake Sammamish, King County. Oligocene.

157

One mile east of locality 156 in Section 14, Township 24 North, Range 5 East. Lower Miocene.

158

One-fourth mile north of Woodman's station on shore of Port Discovery Bay in Section 5, Township 29 North, Range 1 West. Oligocene.

159

Three hundred feet north of locality 158 on east shore of Port Discovery Bay.

160

Bluff at Porter Station in N. P. Railroad cut in Section 22, Township 17 North, Range 4 West. Oligocene.

161

In wagon road cut one-half mile east of Porter in Section 27, Township 17 North, Range 4 West. Oligocene.

162

On western shore, Port Townsend Bay, in Section 36, Township 30 North, Range 1 West. Oligocene.

163

On western shore Port Townsend Bay in Section 36, Township 30 North, Range 1 West. Oligocene.

164

At Restoration Point, Kitsap County.

165

Oak Bay on western shore just south of ship canal spit, in Section 7, Township 29 North, Range 1 East. Oligocene.

166

Six hundred feet west of Porter station in Northern Pacific Railway cut, Section 22, Township 17 North, Range 5 West. Oligocene.

167

Wagon road cut on Wilson Creek, Pacific County, in Section 21, Township 14 North, Range 8 West. Oligocene.

168

Old embankment along Willapa River at trestle in Section 27, Township 14 North, Range 8 West, one-half mile south of Willapa Post Office, Pacific County. Oligocene.

169

Oakville quarry, in sandstone overlying basalt, one mile west of Oakville, Grays Harbor County, on Northern Pacific track. Section 19, Township 16 North, Range 4 West. Oligocene.

170

Half Moon Creek, Pacific County, in Section 34, Township 13 North, Range 7 West.

172

Street cut Columbia City, Seattle, at 50th Avenue South, and one and one-half blocks south of Ferdinand Street. Oligocene.

173

Street grade Columbia City, Seattle, corner 42nd Street and Juneau Street. Oligocene.

176

Bank of small stream entering Satsop River from west, in Section 23, Township 18 North, Range 7 West. Upper Miocene.

174

Bank of small stream entering Satsop River from west, in Section 23, Township 18 North, Range 7 West. Upper Miocene.

175

Bank of small stream entering Satsop River from west, in Section 23, Township 18 North, Range 7 West. Upper Miocene.

177

Ocean cliff south from Hoh River in Section 32, Township 26 North, Range 13 West. Probably upper Miocene. Jefferson County.

178

Bluff along south shore of Strait of Juan de Fuca in Clallam County, one and one-half miles west of Twin Post Office, Section 22, Township 31 North, Range 10 West. Oligocene.

179

1000 feet west of mouth of West Twin River in Section 22, Township 31 North, Range 10 West. Oligocene.

180

Oak Bay, Jefferson County, in cliff in north half of Section 18, Township 29 North, Range 1 East. Oligocene.

181

Cape Elizabeth, Grays Harbor County, Section 34, Township 21 North, Range 13 West. Upper Miocene.

182

Six hundred feet south of Keyhole at Cape Elizabeth, Grays Harbor County. Upper Miocene.

185

One and one-fourth miles north of Point Grenville, Grays Harbor County, Washington, in Section 25, Township 21 North, Range 13 West. Upper Miocene.

187

Cut along street car track in north end of Columbia City, Seattle. Oligocene.

188

King coal mine north of Issaquah, King County, in Section 22, Township 24 North, Range 7 West. Lower Miocene.

189

Conglomerate bank along Silvia Creek, Grays Harbor County, in Section 32, Township 18 North, Range 7 West. Upper Miocene.

192

Columbia City, Seattle, from hill six blocks west of City Hall. Oligocene.

193

Bluff north side of mouth of Raft River, Grays Harbor County, Section 21, Township 23 North, Range 13 West. Upper Miocene.

194

At culvert 38, in bluff along O.-W. R. R. & N. Co. track, 14 miles west of South Montesano, Grays Harbor County. Upper Miocene.

195

Section 25, Township 10 North, Range 9 West. Oligocene. Pacific County.

196

Two miles west of Winlock, Lewis County, in bank of a creek in Section 20, Township 12 North, Range 2 West. Oligocene.

197

Three-fourths mile north of Point Grenville, Grays Harbor County, Washington. Upper Miocene.

199

Cut in left hand branch of Clement's logging road three-fourths mile west of wagon road intersection in Section 20, Township 17 North, Range 7 West.

200

Cut in Northern Pacific Railway one mile east of railroad bridge over Wishkah River at Aberdeen, Grays Harbor County. Upper Miocene. Old locality number 412.

201

One and one-half miles north of Point Grenville in cliffs along ocean.

202

One and three-fourths miles north of Point Grenville in cliffs along ocean.

203

Five hundred feet west of railway station at Porter in cut of Northern Pacific Railway, Grays Harbor County. Former locality 406.

204

Cliff along shore line in northwest quarter, Section 15, Township 22 North, Range 13 West. Upper Miocene. North of Cape Elizabeth.

205

East center portion of Section 9, Township 22 North, Range 13 West, north of Cape Elizabeth. Upper Miocene.

206

Exposure on Germany Creek, Cowlitz County, in Section 12, Township 9 North, Range 4 West. Oligocene.

207

Cut back of Olympic Foundry, South Seattle, King County, in a bluff along east side of Duwamish Valley. Oligocene. North half, Section 20, Township 24 North, Range 4 East.

209

Bluff in main branch of Wishkah River in Section 27, Township 19 North, Range 9 West. Upper Miocene.

215

In Section 29, Township 17 North, Range 8 West, in cut on North River branch of Chicago, Milwaukee & St. Paul Railway.

218

Denny Renton mine Number 2, Second level, in Section 3, Township 22 North, Range 7 East. In brackish water phase of Eocene at Taylor.

219

Denny Renton Coal mine Number 6, at Taylor, King County, in Section 3, Township 22 North, Range 7 East. In brackish water phase of Eocene.

220

One-half mile east of Duwamish in a small creek at a point where a well has been sunk, in northwest quarter, Section 11, Township 23 North, Range 4 East. Eocene brackish water strata.

221

Fossil ledge above Franklin wagon bridge in Green River in Section 10, Township 21 North, Range 7 East. Brackish water Eocene.

222

Cut in Northern Pacific Railway track, one mile south of Duwamish Station, King County, in Section 14, Township 23 North, Range 4 East. Brackish water Eocene.

224

Section 5, Township 18 North, Range 6 West, in logging road cut, Chehalis County. Upper Miocene, coarse grained, cross bedded sandstone.

226

One mile up Olequa Creek above Winlock in Lewis County. Section 29, Township 12 North, Range 2 West. Eocene.

228

Railroad cuts one mile north of Cathcart Station along Northern Pacific Railway. In Section 31, Township 28 North, Range 9 East. Oligocene.

229

Cuts along road and in Wynoochee River banks one mile south of junction with Bitter Creek in Section 35, Township 18 North, Range 8 West. Lower Miocene. Collection of August, 1913. Old locality Number 102.

230

A cut in the North River branch of Chicago, Milwaukee & St. Paul Railway about two miles beyond its junction with the O.-W. R. R. & N. Co. Lower Miocene. Grays Harbor County. Collected July, 1913.

231

Olequa Creek about three-fourths of a mile north of Vader, just south of big bend in creek. A small band of fossils. In Section 29, Township 11 North, Range 2 West. Marine Eocene.

232

West bank and cliff of Cowlitz River, one thousand feet below bend and below locality 233, in Section 11 North, Range 2 West. Marine Eocene.

233

West bank and cliff of Cowlitz River at bend in Section 28, Township 11 North, Range 2 West. Fossils in an excellent state of preservation. Marine Eocene.

234

A narrow band of strata in Olequa Creek about three-fourths of a mile north of Vader just south of big bend in creek. About eight feet stratigraphically above locality 231. In Section 29, Township 11 North, Range 2 West. Marine Eocene.

235

West bank of the mill pond of the O'Connell Lumber Company up Olequa Creek one-half mile above depot at Winlock in Section 28, Township 12 North, Range 2 West. Oligocene. Occurs in residual patches.

236

Stillwater Creek, Lewis County, 2200 feet above its junction with Olequa Creek in Section 30, Township 11 North, Range 2 West. Eocene.

237

Olequa Creek one-fourth mile above Vader Station in east bank of creek just north of point where small creek enters Olequa Creek from the east. In Section 29, Township 11 North, Range 2 West. Eocene.

238

On Olequa Creek three-fourths of a mile north of Vader Station in bend just north of anticlinal axis, about five hundred feet south of locality 231. Section 29, Township 11 North, Range 2 West. Eocene.

239

Northeast quarter of Section 25, Township 11 North, Range 2 West, on east side of Cowlitz River three-fourths of a mile above ferry on Mr. Greece's farm. Oligocene.

240

East bank of Olequa Creek about one-third mile below its junction with Stillwater Creek and just below Northern Pacific Railroad bridge. In Section 32, Township 11 North, Range 2 West. Eocene.

241

Bank of Stillwater Creek about one and one-half miles above junction with Olequa Creek in Section 30, Township 11 North, Range 2 West. Marine Eocene.

242

Between localities 233 and 232 in bank of Cowlitz River in Section 28, Township 11 North, Range 2 West. Eocene.

243

Coal Creek, Cowlitz County, at the main camp of the Inman Polson Logging Company on the north bank of the creek immediately back of the Y. M. C. A. shack. There is a 10-foot bank composed in large part of massed and broken shells, in Section 27, Township 9 North, Range 3 West. Eocene.

244

Bank of Coal Creek, Cowlitz County, about one-half mile below Inman Polson Company's store. Oysters. Section 11, Township 8 North, Range 3 West, near center of section. Eocene.

245

Bank of Coal Creek, Cowlitz County, about one-fourth mile down stream from Inman Polson Company's store. An oyster bed about twelve inches thick. In northeast corner of Section 11, Township 8 North, Range 3 West. Eocene.

246

East bank of Coal Creek about one-fourth mile below school house in a small sandy ledge at foot of cliff. In Section 35, Township 9 North, Range 3 West, near center of section. Eocene.

247

Coal Creek, Cowlitz County, about one and one-half miles below Inman Polson Company's store at the old dam in the extreme southwest quarter of Section 11, Township 8 North, Range 3 West. Eocene.

248

Coal Creek, Cowlitz County, about one and one-fourth miles down stream below Inman Polson Logging Company's store on the east bank in the canyon. In southeast quarter of southeast quarter of Section 10, Township 8 North, Range 3 West.

249

Coal Creek, Cowlitz County, about one and one-fourth miles down stream below Inman Polson Logging Company's store on the west bank of the creek in the canyon and opposite locality 248. Mostly oysters. In Section 10, Township 8 North, Range 3 West. Eocene.

250

Alockaman River in Wahkiakum County about one-half mile above the forks on the east fork. A small ledge at the water's edge at the foot of a 30-foot cliff. Near boundary line between Sections 25 and 24, Township 10 North, Range 5 West. Lower Miocene.

251

Alockaman River in Wahkiakum County near the center of the southeast quarter of Section 26, Township 10 North, Range 5 West, on the Clinton Olmstead homestead. Oligocene.

255

In railroad cut on the O.-W. R. & N. Co. one-fourth mile north of Lincoln Creek Station in Section 26, Township 15 North, Range 3 West. Oligocene.

256

In railroad cut on O.-W. R. R. & N. Co. one mile north of Lincoln Creek Station in Section 27, Township 15 North, Range 3 West. Oligocene.

257

North bank of Columbia River, two hundred feet west of the mouth of Sisson Creek in Wahkiakum County in Section 6, Township 9 North, Range 8 West. Oligocene.

258

One-half mile west of Twin Postoffice, Clallam County, in sea cliff in Section 27, Township 31 North, Range 10 West. Oligocene.

259

Two miles west of Gettysburg, Clallam County, in sea cliff in northwest quarter, Section 29, Township 31 North, Range 9 West. Oligocene.

261

Cliff on north shore of Columbia River about one-half mile east of Knappton, Pacific County. Fossils occur in nodules. In Section 9, Township 9 North, Range 9 West. Oligocene.

262

One and one-eighth miles west of Lincoln Creek Station in bluff along O.-W. R. R. & N. Co. in Lewis County. In Section 26, Township 14 North, Range 3 West. Oligocene.

263

Bluffs along bend in Cowlitz River in Section 28, Township 11 North, Range 2 West. Marine upper Eocene.

264

Bluff on south side of Bear River, Pacific County, on line between Sections 20 and 21, Township 10 North, Range 10 West. Oligocene.

265

Bluff on east side of Shoalwater Bay, Pacific County in Section 29, Township 11 North, Range 10 West. Oligocene.

267

East shore of Port Discovery Bay in Jefferson County in Section 5, Township 29 North, Range 1 West. Oligocene.

268

South shore Strait of Juan de Fuca in Clallam County, about three miles west of Piller Point, in Section 32, Township 31 North, Range 12 West. Lower Miocene.

269

Shore of Strait of Juan de Fuca in Clallam County one mile and a half west of the coal mine in Section 23, Township 32 North, Range 12 West. Lower Miocene.

270

Cliff south shore of Strait of Juan de Fuca in Clallam County in Section 21, Township 32 North, Range 12 West. Lower Miocene.

271

Cliff south shore of Strait of Juan de Fuca in Clallam County in Section 22, Township 31 North, Range 9 West, about one thousand feet west of locality 258. Lower Miocene.

272

Cliff south shore of Strait of Juan de Fuca in Clallam County in Section 19, Township 31 North, Range 9 West. About one mile west of locality 259. Lower Miocene.

273

Cliff south shore of Strait of Juan de Fuca in Clallam County, in Section 24, Township 31 North, Range 10 West, about one-half mile east of east fork of Twin River and just east of rocky bluff. Lower Miocene.

274

Cliff south shore of Strait of Juan de Fuca in Clallam County in Section 21, Township 31 North, Range 10 West. Lower Miocene.

276

Old Washington Geological Survey collection of 1902 from Cowlitz County, in Section 11, Township 9 North, Range 2 West. Eocene. Former locality 3.

277

Old Washington Geological Survey collection of 1902 from Cowlitz County in Section 25, Township 9 North, Range 2 West. The Pecten locality east of Castle Rock. Eocene. Former locality 2.

278

Old Washington Geological Survey collection of 1902 from Cowlitz County in Section 13, Township 9 North, Range 2 West. Eocene. Former locality 4.

279

Old Washington Geological Survey collection of 1902 from Cowlitz County on Arkansas Creek, three miles west of Castle Rock. Eocene. Former locality 5. Pectens are common.

280

Old Washington Geological Survey collection of 1902. From Lewis County in Chehalis hill one-fourth mile southeast of hotel. Eocene. Former locality 6.

281

Old Washington Geological Survey collection of 1902 in Lewis County on Olequa Creek, one mile up creek from Winlock. Former locality 7.

282

Old Washington Geological Survey collection of 1902 in Cowlitz County twelve miles west of Kelso. Eocene. Former locality 8.

283

Old Washington Geological Survey collection of 1902 in Cowlitz County twelve miles west of Kelso. Eocene. Former locality 9.

285

One mile west of Oakville, Grays Harbor County, in Section 19, Township 16 North, Range 4 West. Oligocene.

288

From falls on Scantogrese Creek near Castle Rock in S. E. quarter, Section 18, Township 9 North, Range 2 West. Eocene.

289

Near an old coal prospect in Section 31, Township 10 North, Range 2 West. Eocene.

290

Near Pecten locality in Section 24, Township 9 North, Range 2 West. Eocene.

291

Near Winlock, Lewis County, in Section 28, on Olequa Creek in bluff near junction of west branch of Olequa Creek west from millpond. Oligocene.

292

West branch of Olequa Creek one-half mile above junction of main creek. Oligocene.

293

North end of big slide on N. P. Railway cut one-half mile north of Tenino in Thurston County in Section 17, Township 16 North, Range 1 West. Oligocene.

294

McClarity ranch on south bank of Stillwater Creek one mile west of Vader in Section 30, Township 11 North, Range 2 West. Eocene.

295

One and one-half miles north of Vader in Lewis County in bed of Olequa Creek at milepost 73 on Northern Pacific Railway in Section 20, Township 11 North, Range 2 West. Eocene.

296

On Booth Ranch two and one-quarter miles up Stillwater Creek from junction with Olequa Creek in Section 24, Township 11 North, Range 3 West. Eocene.

297

On Olequa Creek one-eighth mile north of railway station at Vader in Section 29, Township 11 North, Range 2 West. Eocene.

298

Three-fourths mile west of Vader on Stillwater Creek in Section 30, Township 11 North, Range 2 West. Eocene.

299

Rock bluff in N. P. Railway cut 2850 feet south of mile post 76 and three-fourths mile north of Olequa railway station in Section 4, Township 10 North, Range 2 West. Eocene.

300

Banks of Olequa Creek at the old Cantwell place north of Vader in Section 20, Township 11 North, Range 2 West. Eocene.

304

The west end of rock island west of Point Glover quarry near entrance to Bremerton Inlet in Section 8, Township 24 North, Range 2 East. Oligocene.

305

At Bean Point south end of Bainbridge Island in Section 14, Township 24 North, Range 2 East. Middle Oligocene.

INDEX.

Page

Abernathy Creek, Eocene rocks on 154, 155
Acila gettysburgensis zone 81, 166
  Species characteristic of 168, 169
Acknowledgments 13
Admiralty epoch, glaciation of 237
  till 47
Alki Point, Oligocene formations at 186, 192
Alluvial deposits 244
Alockaman River, Eocene formations on 153
  lower Miocene formations on 212
  Oligocene formations on 208
Anticlines 248
  in relation to occurrence of petroleum 263, 264
Arago formation 48
Arca montereyana zone, species of 213
  Rocks of 52, 81, 83
Areas mapped geologically 15
Arnold, Ralph 18, 37, 38, 40, 42, 47
Astoria, formation at 48
  geology at 43
Bailey Peninsula, Oligocene of 191
Bainbridge Island, Oligocene 186
Baker, Mount 55
Bald Hills 87
  Bald Hills area 133, 136
Ballard oil well 297
Basement complex 81
Bayne member of Eocene 112
  stratigraphic section of 112, 113
Bibliography 19
Black Hills area 137, 141
Blake, W. P. 16, 21, 22
Blakeley formation 47
  horizon 81, 166
Blakeley Harbor, rocks at 180
Bogachiel River, formations on 228, 291, 290
  occurrence of gas at 282, 290, 291
Bonser, T. A. 16
Bretz, J. H. 45, 48
Brockett, L. P. 24
Brown, Dr. Robert 16, 22, 23
Carboniferous in Washington, history of 252
Cape Elizabeth 68, 73, 214
  stratigraphic section at 226, 227
Cascade Mountains 32
  geologic structure of 245
Cathlamet area 153, 157
Cedar Mountain area 118, 119
Cedar River, volcanic rocks on 233
Chehalis formation 47, 48
Chico formation 77, 79
  oil well 297

Page
Clallam Bay, occurrence of Oligocene at....199, 202
Clallam County, occurrence of oil in northern....272, 273
oil in southwestern.... 281
Clallam formation....18, 38, 39
Clapp, Charles H.... 19, 45
Clark, Bruce L..... 52
Clark, W. B..... 17, 25
Coal Creek....104, 106
stratigraphic section on.... 109
Coal deposits.... 34
Coast Ranges of Washington.... 56
Collier, A. J..... 49
Columbia City, Oligocene at....186, 190, 191, 192
Columbia Plateau.... 55
Columbia River.... 20, 26
area....207, 209
drainage.... 59
Copalis oil well.... 293
Cowlitz County, occurrence of oil in.... 275
Cowlitz formation.... 47, 52
Cowlitz Valley.... 57, 90
area....159, 163
Pleistocene deposits of.... 243
stratigraphic section in.... 92
Dall, Wm. H....17, 18, 28, 42
Dana, James D.... 16, 20
Darton, N. H.... 44
Dickerson, R. E.... 52
Diller, J. S....26, 32, 34
Donald, J. T.... 23, 25
Drainage.... 54
Drilling operations, record of.... 293
Duwamish, fossils at.... 100
Duwamish Valley, Oligocene in.... 192
Elk Creek, formations near.... 142
Elk River formation.... 47
Empire formation.... 47, 85
Enumclaw volcanic series....232, 234
Eocene....47, 48, 81, 85
climatic conditions during.... 101
condition of deposition of.... 100
fauna of.... 93
faunal lists of....94, 95, 96, 97, 98, 99
geographic distribution of.... 86, 87
lithology of.... 88
stratigraphy of.... 92
thickness of.... 91
Evans, George W.... 46
Evans, Dr. John.... 21
Faults.... 251
Faunal localities in Washington.... 299
Fettke, Charles R.... 16
Field work.... 13
Flattery area....196, 200
Flattery, stratigraphic section at....182, 183
Fluviatile deposits....241, 242, 243
Folding, time of.... 250

	Page
Forks oil well	294
Franklin member of Eocene	113
stratigraphic section of	114
Gas, occurrence of	52
Gas on Bogachiel River	282
Gate City, formation at	141
Geographic distribution of metamorphic rocks	63
Geologic history of western Washington	252
Georgetown, Oligocene at	186, 190, 192
Germany Creek, Eocene formations near	153, 156
Gettysburg, Oligocene at	200
Gibbs, George	21
Gilman, S. C.	27
Glacial deposits, general statement of	236
geographic distribution of	236
Glacial outwash towards Grays Harbor	239, 241, 242
Glacier Peak	55
Grand Ridge	106
Oligocene at	191
Granite Falls	63
Granodiorite	231
Grays Harbor	56
Grays Harbor area	202, 207
anticlines and synclines in	249
stratigraphy of upper Miocene in	225
Grays Harbor County, occurrence of oil in	275
Green River area	110, 118
Greenhow, Robert	19
Gunn Peak formation	63
Hannibal, Harold	19
Harris, G. D.	17, 25
Heer, Oswald	32
Historical review	16
Hoh formation	67, 76
occurrence of oil in	278 to 290
Hoh Head, geology of	73
Hoh Head oil well	294
Hood Canal	59
Hoquiam, formations at	221
Humptulips River, formations on	20, 21, 23
Ilwaco area	157, 159
Index granodiorite	65, 66
Issaquah	108
Juan de Fuca area	196, 200
Juan de Fuca, anticlines and synclines along shores of Strait of	248
Eocene at Strait of	129
lower Miocene at Strait of	212
Kalaloch River, stratigraphic section at	74
Keechelus volcanic series	84
correlation with	234
Kerriston, geologic structure at	123, 124
Kimball, J. P.	17, 29
King, Clarence	22
King County area	186, 192
King County, metamorphic rocks in	63, 64
possible occurrence of oil in	269, 270

Page

Kitsap County, occurrence of Eocene in....133, 134, 135
occurrence of Oligocene in.... 186
occurrence of petroleum in.... 270
Knappton, occurrence of Oligocene at....208, 209
Knowlton, F. H. 17
Kummer member of Eocene.... 116
stratigraphic section of.... 116
Lakes 61
Landes, Henry 34, 35
La Push oil well.... 293
Lawson, Andrew C. 31, 51
Lesquereux, Leo 21
Lewis County, occurrence of oil in.... 275
Lincoln Creek, occurrence of Oligocene at.... 207
Lincoln formation 47, 180, 207
Lincoln horizon 81, 166
Lupton, Charles T. 51
Martinez formation 81, 82
May Creek 107, 108
Meek, F. B. 21, 22
Merced formation 47
Merriam, J. C. 32
Mesozoic, in Washington....253, 254
Metamorphic rocks in western Cascades.... 63
Miocene formations, fauna of upper....214 to 218
general statement of.... 211
geographic distribution of lower.... 211
geographic distribution of upper.... 213
geologic structure of.... 212
lithology of upper.... 213
occurrence of oil in....279, 283, 284
stratigraphy of upper.... 214
Miocene epoch in Washington, history of.... 257
Miocene, general 47, 81
lower 83
list of species in lower....170 to 177
upper 84
Miocene of Astoria and Coos Bay.... 18
Molopophorous lincolnensis zone....81, 166, 180
species characteristic of.... 167
Monterey formation 47, 213
Montesano formation 47, 67, 81, 220, 221
Montesano, Oligocene at.... 205
Nasel River, formations near....147, 149
Neah Bay, formation at.... 182
Newberry, J. S. 21, 22
Newcastle Hills–Grand Ridge area.... 102-109
geologic structure of Eocene in....147, 149
Oligocene of 186, 190
North Head, formations at.... 158
Oakville, Eocene formations near.... 142
Oil, occurrence of.... 52
Okanogan Highlands 55
Olequa Creek, Eocene formations along....159, 161, 162
Olequa formation 48
Oligocene 47, 48, 81, 82
Oligocene epoch in Washington, history of....256, 257

	Page
Oligocene formations, conditions of deposition of	183
faunal zones of	166
general statement of	164
list of species of	170 to 177
lithology of	179
Molopophorous zone of	166
stratigraphy of	179, 180
Olympic Mountains	56, 65
Eocene formations in	87
Olympic Peninsula	18, 38, 40, 258
Ozette Lake area, occurrence of oil in	292
Pacific County, Eocene formations in	145
occurrence of oil in	274
Pacific States oil well	297
Petroleum deposits	259, 263
Petroleum, organic theory for origin of	260, 261
Petroleum, possible occurrence in Cascade Mountains	267
Cowlitz and Lewis counties	275
glacial deposits	267, 279
Grays Harbor County	275
Hoh formation	277, 278
Hoh River area	288
King and Pierce counties	268, 269, 270
Kitsap County	270
north slope Olympic Peninsula	271
Pacific and Wahkiakum counties	274
pre-glacial formations	268
Puget Sound Basin	267
Queniult River area	283, 284
Quillayute River area	290, 291
Quimper Peninsula	271, 272
Queets River area	285, 286, 287
southwest Clallam County	281
southwestern Washington	273
Thurston County	276
Washington	266
western slope of Olympic Peninsula	277
Pierce County, possible occurrence of petroleum in	269
Pleistocene	47
deposits of marine origin	243
formations, general statement of	236
glaciation	48
glaciation in western Washington	237, 258
Pliocene	47, 81
epoch in Washington, history of	257
marine deposits	85
Point of Arches	72
Porter horizon	81, 166
Porter Creek, Oligocene rocks on	180, 206
Port Crescent area	129, 132
Port Discovery Bay, Oligocene on shores of	194
Port Discovery, Eocene formations at	127
Pre-Tertiary formations, general statement of	62
Puget group	16, 17, 47
Puget Sound Basin	33, 57
Puyallup interglacial epoch	239
Pysht, occurrence of Oligocene formations at	199, 202

Page

Quaternary 81, 85
Quaternary epoch in Washington, history of..... 258
Queets River 67, 72, 225
  area, occurrence of oil in..... 285, 286, 287
Queniult oil well..... 296
Queniult River 73, 214, 220, 226
  area, occurrence of oil in..... 283, 284
Quilcene, formations at..... 126, 193, 194
Quillayute River 67, 214
  area 228, 229
    occurrence of oil in..... 290, 291
Quimper Peninsula area, Eocene of..... 125, 127
    Oligocene of 193, 194
Raging River area, Eocene of..... 120, 122
Rainier, Mount 55
Reagan, Albert B. 18, 40, 44
Restoration Point area..... 186, 192
Restoration Point, stratigraphic section at..... 182, 189
Ross, Donald 16
Russell, I. C. 17, 32
Saanich formation 47
Sand dunes 244
San Juan Islands..... 78
San Lorenzo formation..... 48, 164
San Pablo formation..... 84
Seattle, anticlines and synclines in vicinity of..... 249
  formation 48
  Oligocene at 180
Shumard, B. F. 21
Sinclair Inlet, formations on..... 135, 180
Siphonalia sutterensis zone..... 100
Skamokawa River, Eocene in vicinity of..... 151, 152
Smith, E. Eggleston..... 45
Smith, George Otis..... 17, 29, 36, 40
Snoqualmie granodiorite 231, 232
Solduc River, formations on..... 228
Sooke formation 48
South Bend, Eocene at..... 148
South Park, Oligocene at..... 190, 192
Stanton, Timothy W..... 28
St. Helens, Mount..... 55
Stillwater Creek, Eocene formations on..... 159, 161, 162
Stromme, Olaf 16
Synclines in relation to occurrence of petroleum and gas..... 264
Tacoma folio 33
Taylor, igneous dikes at..... 120
  structure at 124
Tejon epoch 255
  formation 47, 48, 52, 82, 100
Terrace deposits, general statement of..... 240
Tertiary, general statement of..... 81
Thurston County, occurrence of oil in..... 276
Tidal flat deposits..... 244
Topography, subdivisions of..... 54
Turritella porterensis zone..... 81, 166, 180
  species characteristic of..... 167, 168
Twin River formation..... 48

Page
Vader, Eocene formations at 163
Vancouver Island 32, 19, 67
  Eocene deposits on 88
Vashon drift 47, 239, 240
Volcanoes in Washington 55, 258
Wahkiakum horizon 81
  formation 47
Washburn, Chester W. 52
Washington Oil Company 282
Weaver, Charles E. 19, 40, 46, 47, 52, 53
White, C. A. 16, 24
Wilkes, Charles 19
Willapa Harbor 56
Willapa Oil Well 296
Willapa River area 145, 153
Willis, Bailey 17, 23, 25, 28, 29, 33
Wilson Creek, Eocene in vicinity of 152
Winlock, Oligocene at 207
Wishkah River, formations along 220, 224
  stratigraphic section along 225
Wynooche River, formations along 220, 221, 223
Yoldia strigata zone 81

PUBLICATIONS

OF THE

WASHINGTON GEOLOGICAL SURVEY

ADDRESS

STATE LIBRARIAN

OLYMPIA, WASHINGTON

Volume 1.—Annual Report for 1901. Part 1, Creation of the State Geological Survey, and An Outline of the Geology of Washington, by Henry Landes; part 2, The Metalliferous Resources of Washington, Except Iron, by Henry Landes, William S. Thyng, D. A. Lyon and Milnor Roberts; part 3, The Non-Metalliferous Resources of Washington, Except Coal, by Henry Landes; part 4, The Iron Ores of Washington, by S. Shedd, and the Coal Deposits of Washington, by Henry Landes; part 5, The Water Resources of Washington, by H. G. Byers, C. A. Ruddy and R. E. Heine; part 6, Bibliography of the Literature Referring to the Geology of Washington, by Ralph Arnold. Out of print.

Volume 2.—Annual Report for 1902. Part 1, The Building and Ornamental Stones of Washington, by S. Shedd; part 2, The Coal Deposits of Washington, by Henry Landes and C. A. Ruddy. Postage 20 cents.

Bulletin 1.—Geology and Ore Deposits of Republic Mining District, by Joseph B. Umpleby. Bound in cloth; price 35 cents.

Bulletin 2.—The Road Materials of Washington, by Henry Landes. Bound in cloth; price, 60 cents.

Bulletin 3.—The Coal Fields of King County, by Geo. W. Evans. Bound in cloth; price, 75 cents.

Bulletin 4.—The Cement Materials of Washington, by S. Shedd. Bound in cloth; price, 75 cents. Paper cover; price, 40 cents.

Bulletin 5.—Geology and Ore Deposits of the Myers Creek and Oroville-Nighthawk Districts, by Joseph B. Umpleby. Bound in cloth; price, 50 cents.

Bulletin 6.—Geology and Ore Deposits of the Blewett Mining District, by Charles E. Weaver. Bound in cloth; price, 50 cents.

Bulletin 7.—Geology and Ore Deposits of the Index Mining District, by Charles E. Weaver. Bound in cloth; price, 50 cents.

Bulletin 8.—Glaciation of the Puget Sound Region, by J. Harlen Bretz. Bound in cloth; price, 60 cents. Paper cover; price, 35 cents.

Bulletin 9.—The Coal Fields of Kittitas County, by E. J. Saunders. Paper cover; price, 40 cents

Bulletin 10.—The Coal Fields of Pierce County, by Joseph Daniels. Bound in cloth; price, 60 cents. Paper cover; price, 40 cents.

Bulletin 11.—The Mineral Resources of Washington, with Statistics for 1912, by Henry Landes. Paper cover; price, 25 cents.

Bulletin 12.—Bibliography of Washington Geology and Geography, by Gretchen O'Donnell. Paper cover; price, 25 cents.

Bulletin 13.—The Tertiary Formations of Western Washington, by Charles E. Weaver. Paper cover; price, 40 cents.

Bulletin 14.—The Quincy Valley Irrigation Project, by Henry Landes, A. W. Mangum, H. K. Benson, E. J. Saunders, and Joseph Jacobs. Paper cover; price, 20 cents.

Bulletin 15.—A Preliminary Report on the Tertiary Paleontology of Western Washington, by Chas. E. Weaver. Paper cover; price, 20 cents.

Bulletin 16.—Geology and Ore Deposits of the Covada Mining District, by Charles E. Weaver. Paper cover; price, 25 cents.

PUBLICATIONS OF THE U. S. GEOLOGICAL SURVEY, IN CO-OPERATION WITH THE WASHINGTON GEOLOGICAL SURVEY.

(For copies of these publications address the Director, U. S. Geological Survey, Washington, D. C. Water-Supply papers may also be obtained, upon request, from the U. S. Geological Survey district office, 406 Federal Building, Tacoma, Washington.)

TOPOGRAPHIC MAPS OF THE FOLLOWING QUADRANGLES.

Mount Vernon, Quincy, Winchester, Moses Lake, Beverly, Red Rock, Cedar Lake, Arlington, Wenatchee, Malaga, Priest Rapids, Coyote Rapids, Chehalis, Hoquiam, Ocosta, Pasco, Prosser, Wallula. Price, 10 cents each.

Power Reports.

Water-Supply Paper No. 253: Water Powers of the Cascade Range, Part I, Southern Washington.

Water-Supply Paper No. 313: Water Powers of the Cascade Range, Part II, Southeastern Washington, Puget Sound Region.

Water-Supply Paper No. 369: Water Powers of the Cascade Range, Part III, Yakima Basin.

Water-Supply Paper No. ——. Water Powers of the Cascade Range, Part IV, Wenatchee and Entiat basins. In preparation.

River Profiles.

Water-Supply Paper No. 346: Profile Surveys of Clark Fork of Columbia River.

Water-Supply Paper No. 366: Profile Surveys of Snoqualmie, Sultan, and Skykomish rivers.

Water-Supply Paper No. 368: Profile Surveys of Wenatchee River and tributaries.

Water-Supply Paper No. 376: Profile Surveys, Chelan and Methow basins.

Water-Supply Paper No. 377: Profile Surveys, Spokane and John Day basins.

Water-Supply Paper No. 419: Profile Surveys in Skagit River Basin. Government Printing Office, Washington, D. C.

Annual Stream-Flow Reports.

Water-Supply Paper No. 272: Surface Water Supply of the United States, North Pacific Coast, 1909.

Water-Supply Paper No. 292: Surface Water Supply of the United States, North Pacific Coast, 1910.

Water-Supply Paper No. 312: Surface Water Supply of the United States, North Pacific Coast, 1911.

Water-Supply Paper No. 332: Surface Water Supply of the United States, North Pacific Coast, 1912.

Water-Supply Paper No. 340: Gaging stations and publications on water resources 1885-1913.

Water-Supply Paper No. 362: Surface Water Supply of the United States, North Pacific Coast, 1913.

Water-Supply Paper No. 392: Surface Water Supply of the United States, North Pacific Coast, 1914. Government Printing Office, Washington, D. C.

Water-Supply Paper No. 412: Surface Water Supply of the United States, North Pacific Coast, 1915. In preparation.

Qualitative Report.

(Principally in cooperation with State Board of Health.)

Water-Supply Paper No. 339: Quality of Surface Waters of Washington.

PUBLICATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE, BUREAU OF SOILS, IN CO-OPERATION WITH THE WASHINGTON GEOLOGICAL SURVEY.

(For copies of these publications address one of the members of congress from Washington.)

Reconnoissance Soil Survey of the Eastern Part of Puget Sound Basin.

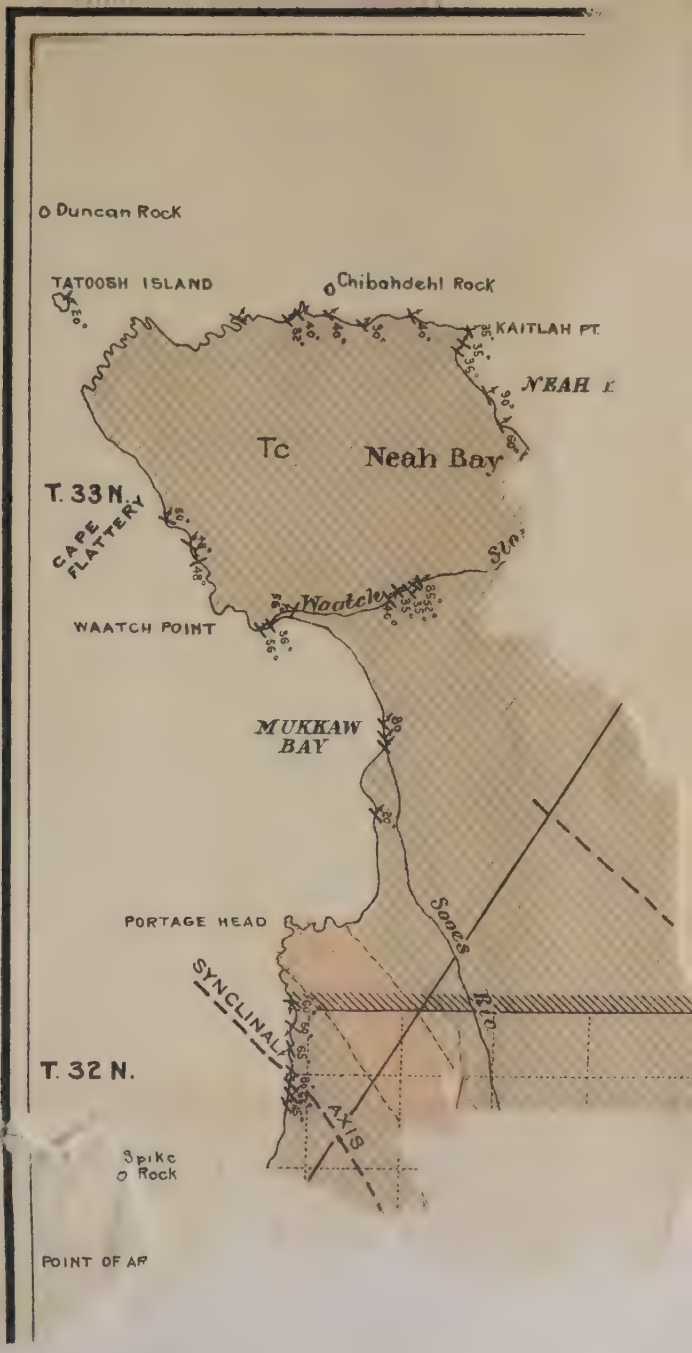
Reconnoissance Soil Survey of the Western and Southern Parts of the Puget Sound Basin.

Reconnoissance Soil Survey of Southwestern Washington.

Reconnoissance Soil Survey of the Quincy Area.

Reconnoissance Soil Survey of Stevens County.

Reconnoissance Soil Survey of Franklin County. In press.


Duncan Rock
TATOOSH ISLAND
Chibahdehl Rock
KAITLAH PT.
NEAH
Tc
Neah Bay
T. 33 N.
CAPE FLATTERY
WAATCH POINT
MUKKAW BAY
PORTAGE HEAD
SYNCLINAL
AXIS
T. 32 N.
Spike Rock
POINT OF AR

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

RENEWED BOOKS ARE SUBJECT TO IMMEDIATE
RECALL

OCT 25 '8

3 1175 00486 6

Nº 714655

Washington (State) Division of Mines and Geology.
Bulletin. (Weaver, C.E.: The Tertiary formations of western Washington)